Bulletin 162

Petroleum Technology 45

DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, SECRETARY

BUREAU OF MINES

VAN. H. MANNING, DIRECTOR

REMOVAL OF THE LIGHTER HYDROCARBONS FROM PETROLEUM BY CONTINUOUS DISTILLATION

WITH ESPECIAL REFERENCE TO PLANTS IN CALIFORNIA

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BY

J. M. WADSWORTH

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First edition. October, 1919.

CONTENTS.

	Page.
Introduction	1
Acknowledgments	3
Plants equipped with conventional stills	4
Plant at Avon, Cal	4
General description	4
Detailed description of apparatus	4
Stills	4
Heat exchangers	5
Condensers	5
Vacuum and pressure valves	6
Residuum coolers	6
Operation of plant	6
Rerunning plant	8
Flexibility	9
Capacity	9
Fire hazard	9
Repairs	9
Fuel consumption	10
Steam consumption	10
Water consumption	10
Cost of operation	10
Cost of plant	11
Rerunning plant	11
Data from experiments	11
Heat exchangers	13
Possible changes and improvements	15
Miscellaneous topping plants	15
Plant constructed after design of A. F. L. Bell	16
General description	16
Detailed description of apparatus	16
Retorts	16
Separating towers	19
Condenser	19
Heat exchanger	21
Steam still	23
Separating tower	23
Condensers and coolers	23
Combination fire and steam stills	25
Operation	25
Rerunning plant	27
Steam consumption	29
Water consumption	30
Flexibility	30
Fire hazard	31
Repairs	31

Miscellaneous topping plants—Continued.
Plant constructed after design of A. F. L. Bell—Continued. Page.
Cost data 31
Cost of labor 31
Cost of topping plant 31
Cost per barrel of capacity 32
Changes and improvements possible 32
Data regarding experiments 33
Heat exchangers 37
Brea plant 38
General description 38
Detailed description of apparatus 38
Pipe retort batteries 38
Boiler still batteries 39
Pipe-retort separating towers 40
Vapor separator for boiler stills 41
Heat exchangers 41
The condensers 41
Residuum coolers 42
Steam stills 43
Heat exchanger 43
Dephlegmators and condensers 43
Method of operation 44
Rerunning plant 44
Capacity 45
Fuel consumption 46
Cost of operation 46
Fire hazard 46
Repairs 46
Changes and improvements possible 47
I. W. Fuqua plant 47
General description 47
Detailed description of apparatus 48
Heaters 48
Separators 49
Condensers 50
Water traps 53
Steam oil warmers 53
Operation 54
Rerunning plant 55
Distillate sample 56
Cost of operation 58
Record of plant performance 62
Heat transfer 64
Fuel consumption 66
Steam consumption 69
Water consumption 69
Fire hazard 70
Repairs 70
Cost of plant 71
Changes and improvements possible 71

Miscellaneous topping plants—Continued. Page.
E. I. Dyer plant, Avila, Cal. 71
General description. 71
Detailed description of apparatus. 72
Stills. 72
Heat exchangers. 72
Condensers. 74
Sprinkler type of condenser. 74
Operation. 74
Efficiency of heat exchange. 79
Steam production. 80
Cost of plant. 80
Brown-Pickering plant. 81
General description. 81
Detailed description of apparatus. 81
Stills. 81
Prewarmers. 82
Condensers. 82
Heat exchangers. 83
Separators. 84
Operation. 84
Prutzman plant. 85
General description. 85
Detailed description of apparatus. 86
Exchangers. 86
Steam stills. 86
Heater and economizer. 87
Condenser. 87
Operation. 87
Trumble topping plants. 88
Fellows plant. 88
General description. 90
Operation. 90
Cost of operation. 91
Vernon plant. 94
General description. 94
Detailed description of apparatus. 94
Heaters. 94
Evaporator. 94
Forty-eight-inch first-run condensers. 97
Forty-eight-inch heat exchangers. 97
Thirty-inch rerun condensers. 97
Jacketed line coolers. 98
Second type of heater. 98
Dephlegmator. 99
Operation. 100
Laboratory distillations. 104
Character of products. 104
Theoretical fuel consumption. 106
Over-all efficiency of the topping plant. 107
Efficiency of heat exchangers. 107
Record of plant performance. 109
Cost of plant. 110

Miscellaneous topping plants—Continued.
Trumble topping plants—Continued. Page.
Coalinga plant 110
Detailed description of apparatus 110
Heaters 110
Evaporator 112
Heat exchangers 112
Condensers 112
Separators 112
Dephlegmators 114
Oil catcher 114
Jacketed line cooler 115
Water traps 116
Cooling towers 117
Boilers and tanks 118
Operation 118
Miscellaneous plant records 120
Record of plant performance 123
Fuel consumption 128
Theoretical fuel consumption 128
Over-all efficiency of topper battery 129
Cost of plant 130
The Martinez plants 130
No. 1 plant 130
Detailed description of apparatus, No. 1 plant 130
Heaters 130
Evaporator 132
Oil catcher 132
Separator 132
Dephlegmators 133
Thirty-inch condensers 133
Forty-eight-inch heat exchangers and condensers 133
Jacketed line coolers 133
Operation of No. 1 plant 134
No. 2 plant 137
Detailed description of apparatus, No. 2 plant 138
Evaporator and heaters 138
Heat exchangers 138
Separators 138
Thirty-inch coolers 138
Thirty-inch vertical condensers 139
Dephlegmators 139
Oil catcher 140
Operation of No. 2 plant 140
Cost of labor 146
Repairs 148
Record of performance of plants 148
Cost of plant 149
Possible changes and improvements 149
Distillation 150
Theoretical fuel consumption 150
Over-all efficiency of the retorts 151
Heater data 151

Page.
Summary 153
Publications of petroleum technology 156
Publications available for free distribution 156
Publications that may be obtained only through the Superintendent of Documents 157
Index 159

TABLES.

		Page.
TABLE 1.	Daily plant temperatures, conventional stills, Avon refinery	7
2.	Results of Engler distillations of condensate from each vapor line in crude battery 2 of Avon refinery, January 29, 1916	8
3.	Detailed costs of two crude batteries at Avon refinery	11
4.	Furnace and stack temperatures, with heat losses and furnace efficiencies, conventional crude stills	12
5.	Average residuum and crude-oil temperatures in the heat exchangers of conventional crude stills during November, 1916	14
6.	Quality of crude oil refined and of fuel consumed in crude stills and pipe retorts, Avon refinery, 1916	28
7.	Barrels of distillate run and products made in steam and combustion stills, Avon refinery, 1916	29
8.	Cost of constructing Bell topping plant, Avon refinery	31
9.	Results of analyses of flue gas in Bell topping plant, Avon refinery	34
10.	Data regarding furnace and stack temperatures in Bell topping plant, Avon refinery	34
11.	Cost of refinery operation and repairs, I. W. Fuqua plant	59
12.	Record of plant operation, I. W. Fuqua topping plant	60
13.	Record of temperatures of water discharge of condenser boxes	63
14.	Records covering rate of heat transfer in jacketed line heat exchangers, I. W. Fuqua topping plant	65
15.	Fuel required to top oils of various water contents, I. W. Fuqua plant	68
16.	Three months' record of crude run and products made in 1912 at Avila plant	77
17.	Three months' record of heat exchangers, Avila plant, 1912	77
18.	Three months' record of distillate made and cooling water used in 1912, Avila plant	79
19.	Record of plant operation, 1917, Prutzman topping plant	88
20.	Record of operation of Fellows topping plant	91
21.	Products and fuel consumption at the Vernon refinery	103
22.	Record of heat exchangers, Vernon refinery	108
23.	Operating costs of the Vernon topping plant, November and December, 1913, and January, 1914	103
24.	Comparison of plant temperatures for months of July (to 18th) and August (to 29th), coolings, Trumble plant	118
25.	Record of operation of Trumble plant at Coalinga during four months of 1916	121
26.	Results of laboratory and of refinery distillations, Trumble refinery at Coalinga	122
27.	Plant temperatures at Trumble plant, Coalinga	122
28.	Record of heat exchangers, Trumble topping plant at Coalinga	125
29.	Record of one month's run, Trumble plants 1 and 2, Martinez	148
30.	Data on heaters at Trumble plant No. 2, Martinez, Cal	152
31.	Summary of topping-plant records showing fuel consumption and products made	153

ILLUSTRATIONS.

		Page.
PLATE I.	Front elevation and section, battery of four conventional crude oil stills, Avon refinery	6
II.	Sectional elevation, battery of four conventional crude oil stills, Avon refinery	8
III.	*A*, General view of conventional stills and condensers, with interconnecting piping; *B*, Battery of conventional stills during construction; *C*, Heat exchanger, below the condenser	10
IV.	Brick stack and flues, Bell topping retorts, Avon refinery	14
V.	Plan and section, Bell topping retorts, Avon refinery	16
VI.	Sections of Bell topping retort, Avon refinery	18
VII.	General arrangement and elevation, Bell topping plant, Avon refinery	20
VIII.	*A*, Right-hand view of Bell retorts during construction; *B*, Front and left-hand view of Bell topping retort during construction; *C*, Front view of Bell retorts, showing Dutch ovens	22
IX.	*A*, Front view of completed units, Bell topping retorts; *B*, Steam stills and separating tower, Bell topping plant	24
X.	Cross section of separating tower, Bell topping plant, Avon refinery	26
XI.	Arrangement of condenser piping, Bell topping plant, Avon refinery	28
XII.	Construction detail for heat exchanger, Bell topping plant, Avon refinery	30
XIII.	Piping arrangement within steam stills, Bell topping plant, Avon refinery	32
XIV.	General arrangement of steam stills and piping, Bell topping plant, Avon refinery	34
XV.	Separating tower for steam and combination stills, Bell topping plant, Avon refinery	36
XVI.	Piping arrangement within combination stills, Bell topping plant, Avon refinery	38
XVII.	*A*, Brea pipe retorts and separating towers; *B*, Brea pipe retorts, with condensers in background	40
XVIII.	*A*, Battery of boiler showing interconnecting piping; *B*, General view of boiler stills, Brea refinery	41
XIX.	*A*, Separating towers, Brea refinery; *B*, Water-cooling towers, I. W. Fuqua's plant	48
XX.	*A*, Battery of retorts during construction, Fuqua plant; *B*, Forward view of retorts showing one with coil removed for repair, Fuqua plant; *C*, General view of Fuqua plant	49
XXI.	*A*, Vapor header feeding the condenser boxes, Fuqua plant; *B*, View of separating towers and hot oil and vapor piping, Fuqua plant	50
XXII.	General layout, Fuqua topping plant, Fellows, Cal	54
XXIII.	Flow chart for vapor distillates and cooling water, Fuqua topping plant, Fellows, Cal	56

Page.

PLATE XXIV. *A*, View of condenser boxes showing water discharge, Fuqua plant; *B*, General view of E. I. Dyer topping plant; *C*, Electrical dehydrating equipment, Dyer topping plant..... 58
XXV. Details of steam still, Dyer topping plant, Avila, Cal..... 72
XXVI. *A*, Forward end of stills showing interconnecting piping, Dyer topping plant; *B*, Heat exchanger tubes, being removed for repairs..... 74
XXVII. *A*, General view of heat exchangers and box condensers, Dyer plant; *B*, Front view of heat exchangers, Dyer plant..... 75
XXVIII. *A*, General view of exchangers and condenser, Dyer plant; *B*, Right-hand view of condensers and exchangers, Dyer plant..... 76
XXIX. Details of heat exchanger, Dyer topping plant, Avila, Cal..... 78
XXX. Details of box condenser, Dyer topping plant, Avila, Cal..... 80
XXXI. Details of spray condenser and supports, Dyer topping plant, Avila, Cal..... 82
XXXII. General arrangement of Dyer topping plant, Avila, Cal..... 84
XXXIII. Interconnecting still piping, Dyer topping plant, Avila, Cal.. 86
XXXIV. *A*, View of Brown-Pickering stills showing heating coils underneath; *B*, General view of boiler prewarmers, stills, and vapor separator, Brown-Pickering plant..... 88
XXXV. *A*, Condensers and heat exchangers, Brown-Pickering plant; *B*, Rear view of the condensers and exchangers, Brown-Pickering plant..... 89
XXXVI. *A*, Pipe retort and prewarmers, Prutzman plant; *B*, 48-inch and 30-inch condensers with jacketed line coolers in foreground, Vernon Trumble plant..... 90
XXXVII. Plan and elevations of heater and economizer, Prutzman topping plant, Betteravia, Cal..... 92
XXXVIII. *A*, Side elevation of the condenser installation, showing dephlegmator and heat exchangers, Vernon Trumble plant; *B*, Close view of dephlegmator and heat exchangers, Vernon Trumble plant..... 94
XXXIX. *A*, Second type of heater, Vernon Trumble plant; *B*, General view of pipe retorts and evaporators, Vernon Trumble plant.. 95
XL. *A*, First type of pipe retorts, Vernon Trumble plant; *B*, View of separators and dephlegmator, Vernon Trumble plant..... 96
XLI. *A*, Coalinga Trumble plant, during construction; *B*, View of condensers, heat exchangers, and separators, Coalinga Trumble plant; *C*, Separators showing dephlegmators and heat exchangers in foreground, Coalinga Trumble plant..... 112
XLII. General arrangement and piping for Trumble refining plant, Coalinga, Cal..... 114
XLIII. Elevations of general arrangement and piping, Trumble refining plant, Coalinga, Cal..... 116
XLIV. *A*, Pipe retorts and evaporator with evaporator column, Trumble No. 1 plant, Martinez, Cal.; *B*, Trumble No. 1 plant, Martinez, Cal..... 132
XLV. *A*, View of pipe retorts showing insulated return bends, Martinez Trumble No. 1 plant; *B*, Condensers with heat exchangers in foreground, Martinez Trumble No. 1 plant; *C*, View of condensers and jacketed line coolers, Martinez Trumble No. 1 plant..... 133

Page.

PLATE XLVI. *A*, Heat exchangers, Martinez Trumble No. 1 plant; *B*, Separators showing steam valves and interconnecting piping, Martinez Trumble No. 1 plant 134
XLVII. Elevations of general arrangement and of vapor and distillate piping, No. 2 Trumble topping plant, Martinez, Cal 138
XLVIII. Plan of general arrangement and of vapor and distillate piping No. 2 Trumble topping plant, Martinez, Cal 140
XLIX. *A*, Rear view of pipe heaters showing Dutch ovens, Trumble No. 2 plant; *B*, General view of Martinez Trumble No. 2 plant showing dephlegmator and heat exchanger installation 142
L. *A*, General view of Trumble No. 2 plant; *B*, View of valve assembly controlling operation, Trumble No. 2 plant 143

FIGURE 1. General arrangement of heat exchanger in Bell topping plant, Avon refinery 22
2. Pipe retorts, Brea topping plant 39
3. Elevation of four 40-horsepower boiler stills, Brea topping plant 40
4. Diagram showing arrangement of oil lines for stills in figure 3 40
5. Dephlegmator and condensers, Brea topping plant 42
6. Crude-oil heaters, I. W. Fuqua topping plant, Fellows, Cal 49
7. Elevation of separating tower, Fuqua topping plant 50
8. Plan of separating tower, Fuqua topping plant 51
9. Details of condensers, Fuqua topping plant 51
10. Crude oil and residuum flow sheet, Fuqua topping plant 54
11. Chart for use in computing fuel consumption at I. W. Fuqua topping plant 67
12. Crude oil, residuum, and vapor-flow sheet, Dyer topping plant 75
13. Rectangular still, Brown-Pickering topping plant, Fullerton, Cal 82
14. General arrangement of Brown-Pickering topping plant, Fullerton, Cal 83
15. Steam still in Prutzman topping plant, Betteravia, Cal 86
16. Vertical tubular condenser, Prutzman topping plant 87
17. General arrangement of Trumble plant at Fellows, Cal 90
18. Evaporator in Trumble plant at Vernon, Cal 95
19. Details of first type of Trumble separator, Fellows and Vernon plants 96
20. Forty-eight-inch condenser and heat exchanger, Trumble plant at Vernon 97
21. Thirty-inch rerun condensers, Trumble plant at Vernon 98
22. Pipe retort and setting, Trumble plant at Vernon 99
23. Sections of rectangular dephlegmator, Trumble plant at Vernon 100
24. Crude-oil and residuum flow sheet, Trumble plant at Vernon 101
25. Vapor and distillate flow sheet, Trumble plant at Vernon 102
26. Pipe retorts and settings, Trumble plant at Coalinga 111
27. Thirty-six-inch heat exchangers and condensers, Trumble plant at Coalinga 112
28. Second type of Trumble separator, used in Coalinga and Martinez plants 113
29. No. 2 type of Trumble dephlegmator, used at Coalinga and Martinez plants 115
30. Oil catcher in Trumble plants at Coalinga and Martinez 116
31. Crude-oil, residuum, and distillate flow sheet, Trumble plant at Coalinga 117

Page.
FIGURE 32. Pipe retorts and settings of Trumble plant No. 1 at Martinez..... 131
33. Evaporator and evaporator column, Trumble plant No. 1 at Martinez..... 132
34. Forty-eight-inch heat exchangers and condensers in Trumble plant No. 1 at Martinez..... 136
35. Crude-oil and residuum flow sheet, Trumble plant No. 1, Martinez. 135
36. Vapor and distillate flow sheet for Trumble plant No. 1 at Martinez. 136
37. Forty-eight-inch heat exchangers in Trumble plant No. 2, Martinez 139
38. Thirty-inch distillate cooler in Trumble plant No. 2, Martinez.... 140
39. Crude-oil and residuum flow sheet for Trumble plant No. 2, Martinez..... 141
40. Cooling water flow sheet, Trumble plant No. 2 at Martinez..... 142
41. Flue gas flow sheet, Trumble plant No. 2 at Martinez..... 143
42. Vapor and distillate flow sheet, Trumble plant No. 2, Martinez... 144
43. Valve chart, distillate system, Trumble plant No. 2, Martinez.... 145
44. Steam flow sheet, Trumble plant No. 2, Martinez..... 146
45. Curves showing results of Engler distillations of products at Trumble plant No. 2, Martinez..... 147

REMOVAL OF THE LIGHTER HYDROCARBONS FROM PETROLEUM BY CONTINUOUS DISTILLATION, WITH ESPECIAL REFERENCE TO PLANTS IN CALIFORNIA.

By J. M. Wadsworth.

INTRODUCTION.

The purpose of this bulletin is to describe the methods of constructing and operating representative types of plants in the United States used for removing the light hydrocarbons from petroleum by continuous distillation, such plants being commonly known in the trade as topping or skimming plants.

In the discussion of each plant an endeavor has been made to arrange the text similarly in order to facilitate comparison and to emphasize the important features. The various experimental values for the specific and the latent heats of the oils apply approximately to the oil treated. Careful experiments with each oil and its commercial fractions were not justifiable in view of the purpose of this report.

It is regretted that limitations for recording data at the different plants made impossible the determination of a heat balance for each, which would have provided an equitable method of comparing efficiencies. The writer has confined himself to a comparison of the relative efficiencies of the distilling apparatus alone by the following method:

$$\text{Efficiency of stills and settings} = \frac{\text{Heat theoretically required.}}{\text{Heat content of fuel consumed.}}$$

The plants described are all in California where the topping industry has had its growth accentuated by the character and the use of the oil handled. The scarcity of suitable coal made the adoption of other fuel necessary, and the heavy oil of California supplied the need. To raise the flash point and to dehydrate this oil, various plants have been developed. However, the topping industry is represented in other fields; the Roxana Petroleum Co. of Cushing, Okla., and the Warner-Quinlan Asphalt Co. of New Jersey, are operating Trumble plants, and Texas and Oklahoma operators have been experimenting with different pipe retorts for continuous run-

ning. In addition to the reasons for topping cited above, in California topping has other purposes which give the plants practically a universal field in the oil industry. These additional purposes are (1) to remove the lighter constituents of the oil prior to storage for a long period, thus reducing the losses from evaporation, (2) to dehydrate and clean the oil, and (3) in conjunction with a complete refinery, to remove the lighter fractions cheaply and quickly, leaving a residue to be rerun for lubricants, coke, and other products.

The reader in studying a plant for possible adaption to his own use should note that local considerations enter into the design and size of a plant. Several questions present themselves, as follows:

1. What type is suitable for the oil?
2. How much money is available for construction?
3. Will the volume of residuum be large enough for heat exchange with the crude?
4. Can the heat content of the vapors be used to reduce the cooling-water requirements?
5. What method will best recover the heat from stack gases?
6. Are the various pieces of apparatus adequate in size and best adapted to their purpose?
7. Is every possible provision made for the recovery of waste heat?
8. What products will be made, and what volume of each?
9. Is there provision for the recovery of light vapors?
10. Will the saving of fuel justify the capital and maintenance charges on the regenerative apparatus contemplated?

It is regretted that information concerning the operation of topping plants with eastern and Middle West oils is not available. The writer carefully canvassed the Middle West, but did not find a plant where operation had progressed beyond the early experimental stages and reliable figures could be furnished.

The reader will find fuel economy and heat recovery emphasized throughout the descriptions. The conservation of the available petroleum supply is of the utmost importance, and the Bureau of Mines presents this paper to encourage the hearty cooperation of operators to that end.

The Baumé gravity scale used throughout the report is that of Tagliabue with a modulus of 141.5 for conversion to specific gravity.

ACKNOWLEDGMENTS.

The writer wishes to acknowledge the hearty cooperation of all the refiners he interviewed in connection with this report. They have uniformly displayed the liveliest interest in the work. In particular, he desires to thank N. W. Thompson, chief engineer of the Simplex Refining Co., San Francisco, Cal., and A. F. L. Bell, chief engineer of the Associated Oil Co., San Francisco, Cal., for their valuable criticisms and reviews and for many of the photographs reproduced in this report. E. I. Dyer, manufacturing manager of the Union Oil Co., Los Angeles, Cal.; W. A. Williams, assistant general manager of the Empire Gas & Fuel Co. of Oklahoma; Walter Miller, general superintendent of the Pierce Oil Corporation, Tulsa, Okla.; E. P. Ripley, manager of the Santa Fe Oil Co., Los Angeles, Cal.; G. Van Senden, superintendent of the Shell Co. Refinery, Martinez, Cal.; Chris Stamm, superintendent of the Associated Oil Refinery, Avon, Cal.; H. H. Beers, manager of the construction department of the Shell Co. of California; Frank Milliff, manager of the Milliff Refining Co., San Francisco, Cal.; and Paul Prutzman, Santa Maria, Cal., have also all materially assisted in the preparation of the report. Finally, the writer makes hearty acknowledgment of valuable criticisms and suggestions of Chester Naramore, chief petroleum technologist of the Bureau of Mines, and of the careful and patient clerical work of J. G. Shumate and of Miss H. M. Lansche in checking and copying the manuscript. Their labors have materially increased the value of the paper.

PLANTS EQUIPPED WITH CONVENTIONAL STILLS.

PLANT AT AVON, CAL.

GENERAL DESCRIPTION.

In connection with the topping plant of A. F. L. Bell's design, described in a subsequent chapter, the Avon refinery operates an additional plant of two batteries of four 600-barrel cylindrical stills. The four stills in each battery are interconnected for continuous distillation and are used for topping the crude oil received at the refinery. The entire refinery tops about 20,000 barrels of dry oil, of 26° B. (0.8974 specific gravity), daily, of which about 13,000 barrels are handled with the two batteries of stills.

In general, this plant comprises the two batteries, each of four stills, served by eight rectangular box condensers, and two heat exchangers. Two residuum cooling coils are also provided to cool further the residuum from the exchangers when necessary.

DETAILED DESCRIPTION OF APPARATUS.

STILLS.

The stills are horizontal cylinders, each 10 feet in diameter and 40 feet long, constructed of ½-inch riveted steel plates and fitted with convex ends. They are supported by eight cast-steel lugs, riveted to each side of the shell, which slide on steel plates resting on horizontal 12-inch I beams. The I beams parallel the stills and are carried by four cast-iron columns at an elevation 12 feet 5¼ inches above the concrete foundations. Four stills are placed on adjacent settings to form a battery, and the four columns between each still carry both I beams.

Each still has a 4-foot dome on top near one end, a handwheel on top for operating an elbow plug valve in the 6-inch draw-off, riveted to the bottom at one end, and a 20-inch cast-iron manhole at the center on top. Each end is fitted with a 24-inch cast-steel clean-out door, centered 3 feet from the center line of the still, and several small flanges for steam lines. The supporting lugs are arranged to give the still a fall of 6 inches in its length to the draw-off connection.

The setting for a battery is arranged as follows: On both sides of each still 17-inch red-brick walls, paralleling the line of supporting columns, are constructed on a 1-to-6 batter to the top of the columns.

These walls spring from a line 3 feet 6 inches from the center line of the columns, are 42 feet 8 inches long, and are faced with fire brick for a distance of 18 feet 3 inches from the front of the battery. At the rear end of each still a red-brick wall 2 feet 1½ inches thick, built to fit closely around the lower half of the still, incloses the space between the battered walls. At the front, an 18-inch wall similarly built incloses the space under the still between the side walls. Seventeen feet back from this wall a division wall 4 feet 4½ inches high, faced with fire brick, forms the combustion chamber.

Near the rear wall a second division wall, 6 feet high, forces the escaping combustion gases against the still bottom in their exit through a 3-foot underground flue below the rear wall.

Completely inclosing the entire battery, a second red-brick wall 13 inches thick is constructed to permit a 2-inch air space in the front and rear of the stills. Air holes admit air to this space in the rear of each still, and the space inclosing the columns is baffled to force the air over the entire outside surface of the battered walls. In front the air spaces terminate in the opening for the burner, and dampers are provided on each side to control the air used. Above the air spaces the outer and inner walls at both ends of the battery converge as one wall and are constructed to the middle level of the stills. Clean-out doors and draw-off connections project through these walls. The battery is appropriately stayed with buck stays and tie rods at intervals in both directions.

The upper half of each still is covered with sheets of asbestos under one layer of hollow tile, which in turn is given a coating of cement plaster to make the covering waterproof. Galvanized iron gutters placed between the stills carry the water to down spouts outside the battery. Plates I and II (pp. 6 and 8) show elevations and sections and Plate III (p. 10) shows different views of this still battery.

HEAT EXCHANGERS.

The heat exchangers consist of four rows each of five 9-inch casings, 48 feet long, laid parallel to each other and connected end to end by special castings, to form a continuous coil. Within the 9-inch casing are five 2-inch pipes also connected to form five 2-inch continuous coils. This construction is identical to that of the exchangers described in the discussion of the Bell plant (p. 21), except for the size of the outside jacket. Plate III, *C*, shows this heat-exchanger installation below the condenser boxes.

CONDENSERS.

The condensers each consist of a steel box 15 feet wide by 30 feet long and 11 feet deep, containing a continuous coil of cast-iron pipe of diminishing sizes. They are fully described and illustrated in the discussion of the Bell plant.

VACUUM AND PRESSURE VALVES.

Each still is equipped with a pressure and vacuum relief valve regulated to normal operating conditions. These are set at the condensers on the 12-inch vapor take-off from the still domes.

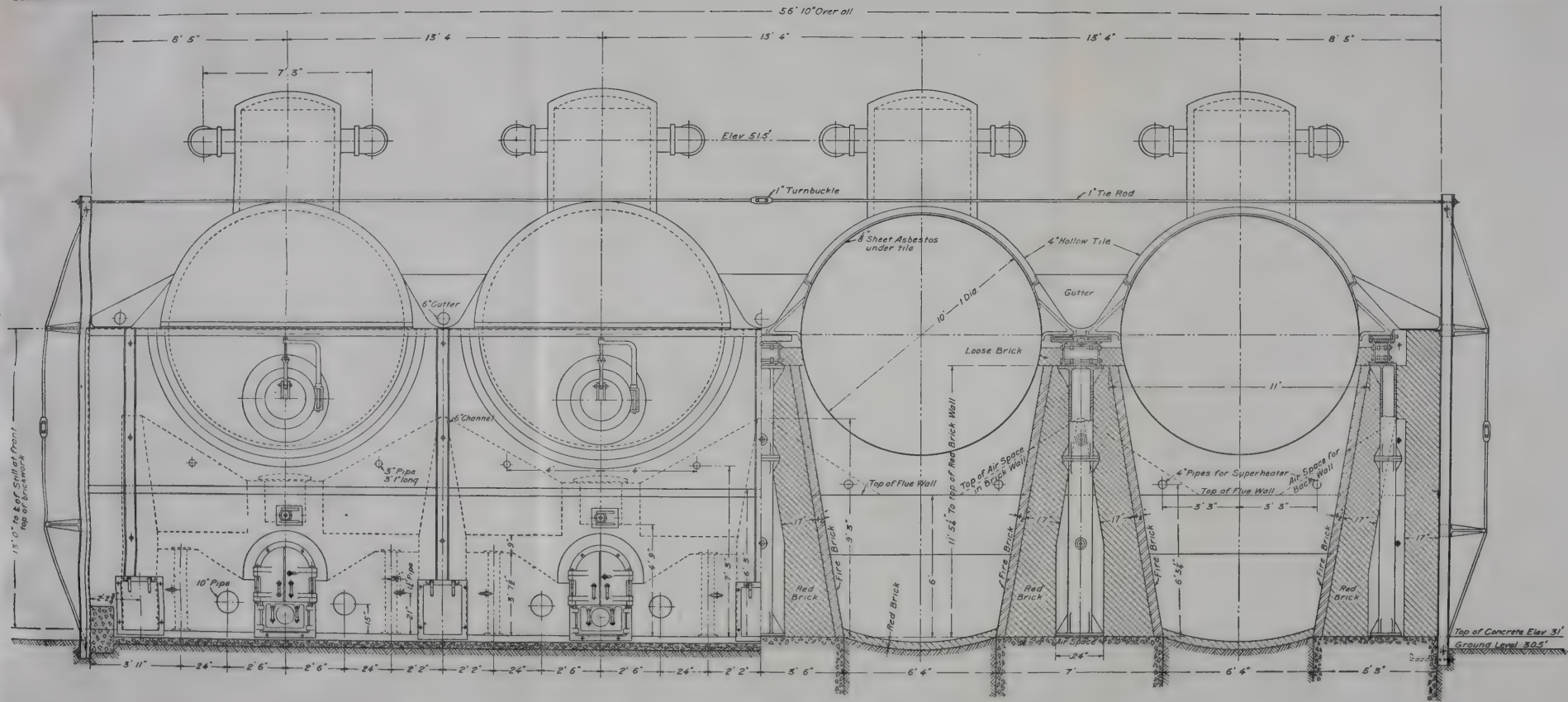
RESIDUUM COOLERS.

The coolers each consist of one horizontal row of eight 4-inch cast-iron pipes 48 feet long connected end to end by flanged return bends, the coil thus constructed being submerged in a shallow concrete reservoir for the cooling water.

OPERATION OF PLANT.

Crude oil before reaching the plant, passes through a horizontal cylindrical tank of about 300-barrel capacity, which is placed in the line. By reason of the lessened velocity in this tank any moisture in the oil settles there and is drained away at periods during the day. Two Dow duplex pumps, 8 by 8½ by 10 inches, receive the oil from this tank, each feeding a heat exchanger and its accompanying battery of stills. The oil is forced through the 2-inch tubes of the heat exchanger countercurrent to the hot residuum leaving the plant, and enters the first still of the battery on the rear end at an average temperature of about 260° F. (126.7° C.). Thence it flows in turn to each still, receiving an additional increment of heat until the fourth and hottest still is reached. "Bottom steam" is used in each still for agitation and for assisting the vapors to pass over. Two 12-inch vapor take-off lines leave the dome of each still, each being connected to a separate condenser. The vapors from each still are condensed and the condensate flows to a single run-down tank to be rerun in the combination or steam stills. Oil leaving the fourth still is received by an 8 by 8½ by 10 inch Dow duplex pump and forced through the jacket of the heat exchanger to the residuum cooler and finally to storage as residuum.

Table 1, following, gives a series of daily readings of plant temperatures and the gravity of distillates given off from each still, with the gravity and the flash point of the resulting residuum.



FRONT ELEVATION AND SECTION, BATTERY OF FOUR CONVENTIONAL CRUDE OIL STILLS, AVON REFINERY.

TABLE 1.—*Daily plant temperatures, conventional stills, Avon refinery.*

Battery.	Gravity of crude run.		Temperature of ingoing crude.		Still 1.				Still 2.				Still 3.				Still 4.				Residuum.			
					Temperature of vapors.		Gravity of distillate.		Temperature of vapors.		Gravity of distillate.		Temperature of vapors.		Gravity of distillate.		Temperature of vapors.		Gravity of distillate.		Gravity.		Flash point.[a]	
	°B.	Specific gravity.	°F.	°C.	°F.	°C.	°B.	Specific gravity.	°F.	°C.	°B.	Specific gravity.	°F.	°C.	°B.	Specific gravity.	°C.	°F.	°B.	Specific gravity.	°B.	Specific gravity.	°F.	°C.
1	26.6	0.8945	265	129.40	290	143.3	58.3	0.7435	340	171.1	52.6	0.7667	386	196.65	47.5	0.7887	415	212.7	43.0	0.809	20.4	0.931	158	70.0
1	26.7	.8935	250	121.0	290	143.3	.....	.....	340	171.1	56.5	.7507	390	198.9	47.3	.7896	415	212.7	43.7	.806	20.4	.931	159	70.55
1	25.6	.900	260	126.7	287	141.65	58.3	.7435	340	171.1	52.5	.767	390	198.9	47.0	.7910	415	212.7	43.5	.807	20.0	.933	144	62.20
2	26.7	.8935	250	121.0	285	140.55	58.5	.7427	340	171.1	53.0	.765	387	197.4	47.5	.7887	415	212.7	43.8	.8055	20.4	.931	170	76.65
2	25.6	.900	250	121.0	290	143.3	58.3	.7435	340	171.1	52.4	.7675	390	198.9	47.7	.7878	415	212.7	43.6	.8065	20.0	.933	156	68.85

[a] Open cup tester.

These stills are fired with oil, atomized by steam through a fish-tail burner, the air required for combustion being supplied directly through the 10-inch nipples and the furnace door in the front of the battery.

RERUNNING PLANT.

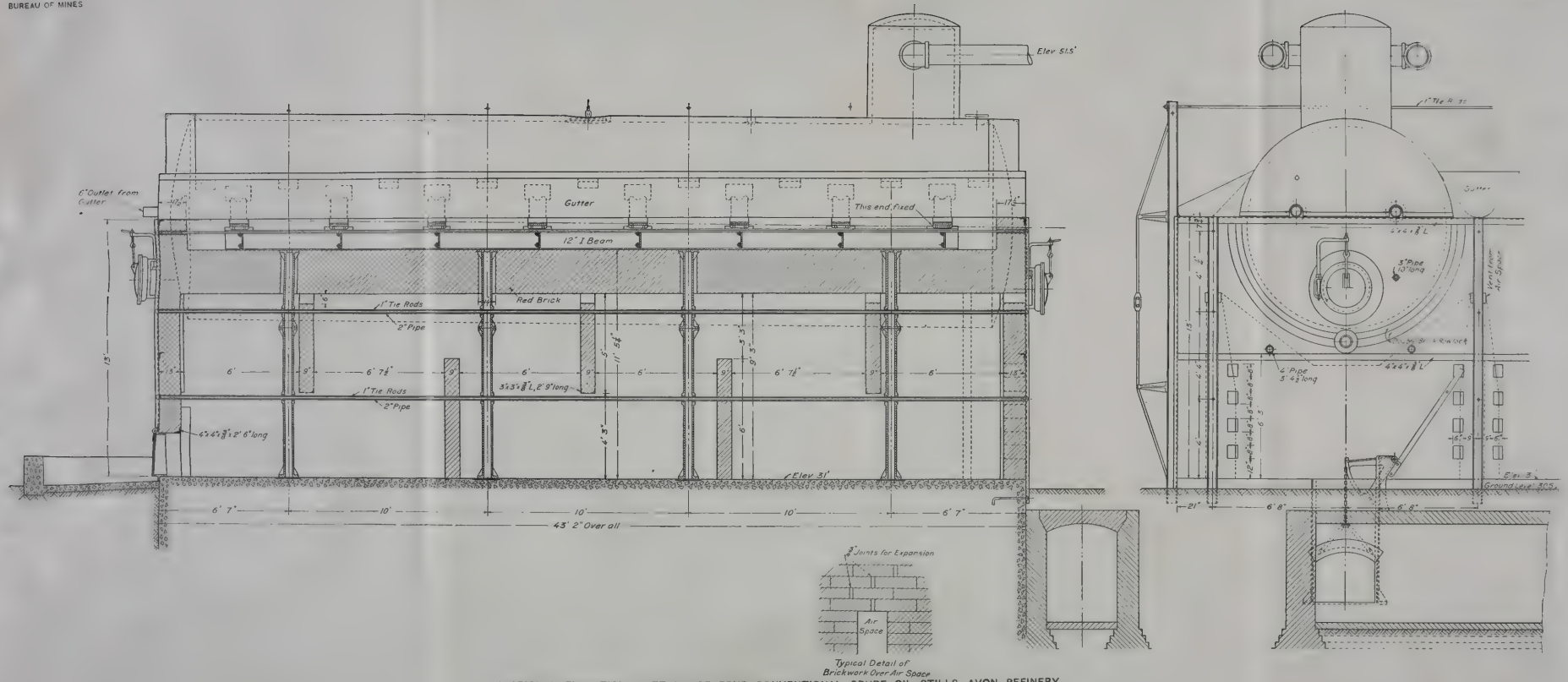
Rerunning of the distillates from the crude stills is done in a battery of four combination steam and fire stills and two steam stills; their construction and operation are fully treated in the subsequent discussion of the Bell topping plant. It is impossible to record separately the performance of the rerunning plant in treating the first-run distillates from these stills to treating the first-run distillates from the Bell plant. However, Tables 6 and 7 (pp. 28 and 29) give the crude oil handled during 1916, by months, for the crude stills, and a complete statement regarding the distillates manufactured in rerunning. The amount of this distillate resulting from the crude stills can only be approximated by considering it as a ratio proportional to the entire crude run in the refinery.

The following results of Engler distillations made by the refinery chemist, William H. Peterson, will assist in comparing the performance of the crude stills to that of the toppers and will indicate the nature of the oil handled.

TABLE 2.—*Results of Engler distillations of condensate from each vapor line in crude battery 2 of Avon refinery, January 29, 1916.*

Still 1 condensate, gravity 58.7° B. (specific gravity, 0.742).			Still 2 condensate, gravity 52.5° B. (specific gravity, 0.767).		
Boiling point.		Per cent over.	Boiling point.		Per cent over.
°F.	°C.		°F.	°C.	
100 to 167	37.8 to 75	11.5	149 to 167	65 to 75	1.5
167 to 212	75 to 100	29.5	167 to 212	75 to 100	15.0
212 to 250	100 to 121.2	26.5	212 to 250	100 to 121.2	32.0
250 to 300	121.2 to 148.8	18.5	250 to 300	121.2 to 148.8	24.5
300 to 350	148.8 to 176.65	8.5	300 to 350	148.8 to 176.65	14.5
350 to 400	176.65 to 204.40	2.5	350 to 400	176.65 to 204.40	6.5
Bottoms		2.1	Bottoms		5.9
Total		99.1	Total		99.9

Still 3 condensate, gravity 47.1° B. (specific gravity, 0.7905).			Still 4 condensate, gravity 42.9° B. (specific gravity, 0.8095).		
198 to 212	92.2 to 100	1.0	230 to 250	110 to 121.2	4.5
212 to 250	100 to 121.2	18.5	250 to 300	121.2 to 148.8	23.0
250 to 300	121.2 to 148.8	30.0	300 to 350	148.8 to 176.65	25.5
300 to 350	148.8 to 176.65	23.0	350 to 400	176.65 to 204.4	20.0
350 to 400	176.65 to 204.40	13.5	Bottoms		27.0
Bottoms		14.0	Total		100.0
Total		100.0			



SECTIONAL ELEVATION, BATTERY OF FOUR CONVENTIONAL CRUDE OIL STILLS, AVON REFINERY.

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Results of Engler distillations of first-run distillate.

[Combined product of the four stills.]

Sample 1, gravity 49.5° B. (specific gravity, 0.780).			Sample 2, gravity 49.6° B. (specific gravity, 0.7795).			Sample 3, gravity 49.6° B. (specific gravity, 0.7795).		
Boiling point.		Per cent over.	Boiling point.		Per cent over.	Boiling point.		Per cent over.
°F.	°C.		°F.	°C.		°F.	°C.	
144–212....	61.65 to 100	11.6	145–212...	62.75 to 100	11.5	144–212...	61.65 to 100	12.0
212–250....	100 to 121.1	22.0	212–250...	100 to 121.1	22.0	212–250...	100 to 121.1	20.5
250–300....	121.1 to 148.8	24.5	250–300...	121.1 to 148.8	25.0	250–300...	121.1 to 148.8	25.5
300–350....	148.8 to 176.65	17.5	300–350...	148.8 to 176.65	17.5	300–350...	148.8 to 176.65	17.5
350–400....	176.65 to 204.40	10.5	350–400...	176.65 to 204.4	10.5	350–400...	176.65 to 204.4	10.0
Bottoms..	.....	13.5	Bottoms..	.....	13.0	Bottoms..	.....	13.5
Total..	.....	99.5	Total..	.....	99.5	Total..	.....	99.0

FLEXIBILITY.

These stills are adapted to running any grade of dry oil, either for topping only or for complete reduction; however, they will not, unless operated under pressure, handle a wet oil without foaming. The distillates from each still are water-white sweet products, comparing favorably in color and odor with the steam-still products.

CAPACITY.

An average for the year 1916 shows the daily normal capacity of each battery to be 6,696 barrels when running an oil of 26° B. gravity (specific gravity 0.897) at a temperature of 400 to 450° F. (204.4 to 232.2° C.) for topping only.

FIRE HAZARD.

Since their construction, these stills have been operating continuously without a fire, owing probably to the fact that they have always handled a clean oil for light topping only. The seams exposed to the fire frequently leak, owing to stresses from unequal expansion, but the small blaze resulting usually cokes over the leak and stops the trouble before any damage can result. It is practically impossible to make continuously oil tight a riveted seam on the fire sheets of the still.

REPAIRS.

Repairs have been neglible, and the only shut-downs have been for cleaning the stills at intervals. In general, any repair with these stills requires a longer shut-down than for the Bell topper because the setting must be allowed to cool enough to permit the entrance of workmen.

FUEL CONSUMPTION.

Table 6 (p. 28) gives the average monthly value of fuel consumption for the year 1916 as 4,507.52 barrels for topping an average of 401,853.1 barrels monthly, the fuel consumption being thus approximately 1.1 per cent of the crude run, no allowance being made for the fuel used in making the steam admitted to the stills.

STEAM CONSUMPTION.

At the plant no attempt is made to measure the quantity of steam consumed for agitation and in the burners. The writer wished to procure enough information on steam consumption to enable him to compare the stills and the toppers, but as the steam made is prorated by an arbitrary schedule to the different apparatus using it, no reliable data were available.

WATER CONSUMPTION.

The cooling water used in the condensers is salt water supplied from the bay by two 8-inch centrifugal pumps direct connected to two 50-horsepower motors. The quantity used varies with the weather and with the nature of the products handled, but an average value of 14 barrels of water to 1 barrel of distillate made covers normal conditions. Except for the power required to lift the water, no operating charge attaches to this part of the plant.

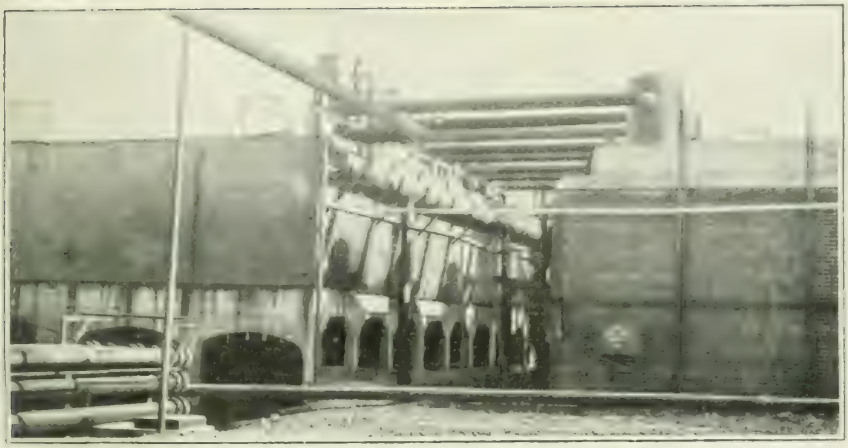
COST OF OPERATION.

The daily labor charge against the entire refinery is represented by the pay roll following. Of the total amount of $76.97, the crude stills should be charged in proportion to the crude handled by them as compared with the entire capacity of the plant.

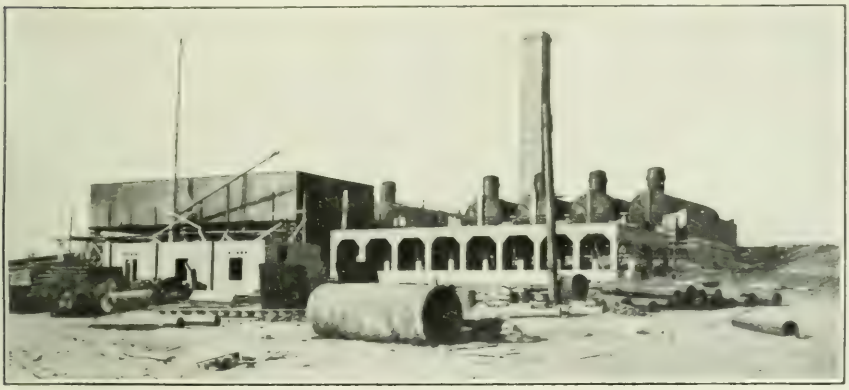
Daily pay roll at Avon refinery.

Two shifts:	
1 stillsman, at $4.16	$8.32
1 fireman, at $3.50	7.00
1 helper, at $3	6.00
1 boiler engineer, at $3.50	7.00
1 pumpman, at $3.50	7.00
1 helper, at $3	6.00
Daily:	
1 gager	4.16
1 chemist	5.00
1 assistant chemist	2.83
Office force and superintendent	23.66
Total (24-hour day), [a]76.97.	

[a] This represents a charge of about $52.50 against these stills, based on the proportion of crude handled to the entire refinery capacity.



A. GENERAL VIEW OF CONVENTIONAL STILLS AND CONDENSERS, WITH INTERCONNECTING PIPING.



B. BATTERY OF CONVENTIONAL STILLS DURING CONSTRUCTION.

C. HEAT EXCHANGER, BELOW THE CONDENSER.

COST OF PLANT.

The estimated cost of the two crude batteries with their condensers and interconnecting piping and pumps, based on costs at the time of construction, is shown in Table 3 following.

TABLE 3.—*Detailed costs of two crude batteries at Avon refinery.*

[Based on prices at time of construction, 1912.]

Item.	Excavation.	Concrete.	Brickwork.	Ironwork.	Unit.	Pumps.	Pipe covering.	Piping	Total.
8 stills	$1,800	$5,000	$13,000	$9,500	$18,000	$1,055	$100	$6,744	$55,199
8 condensers	632	5,104	.....	2,224	9,199	.....	.....	13,903	31,062
2 heat exchangers	.....	500	.....	904	.....	.....	.....	6,120	7,524
1 residuum cooler	.....	.....	.....	.....	.....	.....	.....	750	750
Tail house, three look boxes	49	664	.....	262	2,000	.....	.....	5,120	8,095
Oil-pump plant [a]	400	1,322	.....	1,025	5,000	16,096	75	2,700	18,100
Salt-water plant [a]	99	575	.....	114	375	2,550	.....	375	2,780
Boiler plant [a]	480	1,718	3,272	1,636	16,955	9,718	428	3,300	25,565
Total	3,460	14,883	16,272	15,665	51,529	29,419	603	39,012	149,015

[a] Only that proportion chargeable to the conventional crude still plant is carried to the total column.

RERUNNING PLANT.

The estimated cost of the rerunning plant is given in the description of the topping plant. An amount proportional to the distillate handled from these crude stills should be charged to them. The total estimated cost of the crude batteries and the necessary rerunning apparatus is therefore $224,945, or approximately $16.80 per barrel of normal daily capacity. This figure is considerably higher than the cost of the toppers of similar duty, mentioned later.

DATA FROM EXPERIMENTS.

During the writer's inspection of the plant various experiments were made to determine the efficiency of the different apparatus. Owing to the lack of facilities, these experiments were necessarily incomplete, but the details obtained and the computed results are listed in the following pages.

An ultimate analysis of the fuel oil used at the plant follows:

	Per cent.
Carbon	85.6
Hydrogen	11.89
Oxygen	.9
Nitrogen	.52
Sulphur	1.09

Calorific value, 18,640 B. t. u. (4,697.28 calories).

The theoretical fuel consumption for removing a 25 per cent cut from 1 pound of oil as fractionated below would be as follows, if no heat is lost in the batteries and the heat recovered in the exchangers is considered:

Where the mean specific heat of the oil=0.45, approximately, latent heat of distillate=125 B. t. u., or 31.5 calories, approximately, specific heat of the vapors=0.50 B. t. u., approximately, oil leaves the exchangers at 250° F. (121.1° C.), approximately, the heat required is as follows:

		B. t. u.
Heat 0.938 pound of oil 250–300° F. (121.1–148.8° C.)	0.938 (250–300° F. 121.1–143.8° C.) × 0.45	=21.12
Evaporate 0.058 pound of vapors	.058 × 125	= 7.25
Heat 0.879 pound of oil 300–350° F	.879 (300–350° F.) ×	.45=19.80
Evaporate 0.0346 pound of vapors	.0346 × 125	= 4.33
Heat 0.845 pound of oil 350–400° F	.845 (350–400° F.) ×	.45=19.00
Evaporate 0.024 pound of vapor	.024 × 125	= 3.00
Heat 0.820 pound of oil 400–450° F	.820 (400–450° F.) ×	.45=18.45
Evaporate 0.030 pound of vapors	.030 × 125	= 3.75
		96.70

Heat consumed per pound of oil topped at 100 per cent efficiency=96.70 B. t. u., or 24.40 calories.

Fractionation of oil sample.

[Gravity, 25.6°B. (0.900).]

Boiling point.		Specific gravity of fraction.	Percentage of crude evaporating.		Specific gravity of fraction.	Residue remaining.	
°F.	°C.		By volume.	By weight.		By volume.	By weight.
160 to 212	71 to 100	0.700	2.5	1.94	0.906	97.5	98.06
212 to 250	100 to 121.1	.720	5.25	4.26	.917	92.25	93.80
250 to 300	121.1 to 148.8	.742	7.00	5.84	.918	85.25	87.96
300 to 350	148.8 to 176.65	.767	4.00	3.46	.923	81.25	84.50
350 to 400	176.65 to 204.4	.790	2.75	2.45	.925	78.50	82.05
400 to 450	204.4 to 232.2	.806	3.38	3.07	.932	75.12	78.98

TABLE 4.—*Furnace and stack temperatures, with heat losses and furnace efficiencies, conventional crude stills.*

Apparatus.	Number of test.	Flue-gas analyses.								Air required per pound of fuel.	Air used per pound of fuel.	Per cent of excess air.	Weight of flue gas per pound of fuel.
		Per cent by volume.				Per cent by weight.							
		CO_2.	O.	CO.	N.	CO_2.	O.	CO.	N.				
										Pounds.	*Pounds.*		*Pounds.*
Crude stills	1	5.8	13.8	.....	80.4	8.63	15.0	.....	76.4	13.96	36.88	165	36.76
Do	2	5.2	13.4	.....	81.4	7.8	14.6	.....	78.0	.....	40.56	191	39.41
Do	3	7.3	12.4	.....	80.3	10.8	13.4	.....	75.6	.....	28.60	104	28.76

TABLE 4.—*Furnace and stack temperatures, with heat losses and furnace efficiencies, conventional crude stills*—Continued.

Apparatus.	Number of test.	Atmospheric temperature.		Stack draft.	Observed furnace temperature.	Stack temperature.		Weight of gases per pound of fuel.	Computed temperature of products of combustion.	
		°F.	°C.	Inches of water.		°F.	°C.	Pounds.	°F.	°C.
Crude stills	1	58	14.4	.....	.....	665	351.6	36.76	2,023	1,106.1
Do	2	60	15.55	0.70	.....	650	343.3	39.41	1,892	1,033.3
Do	3	60	15.55	.62	.....	650	343.3	28.76	2,592	1,422.2

Apparatus.	Number of test.	Heat loss from excess air.		Fuel loss.	Furnace efficiency.	Remarks.
		B. t. u.	Calories.	Per cent.	Per cent.	
Crude stills	1	3,477	875	18.6	38.0	Normal operation.
Do	2	3,918	986	21.0	34.6	Dampers one-fifth open.
Do	3	2,159	544	11.6	48.5	Dampers one-seventh open.

One barrel of 26° B. (specific gravity, 0.8974) oil weighs 314.4 pounds; therefore the total heat required to top 1 barrel of this oil at 100 per cent efficiency would be $96.70 \times 314.4 = 30,402.48$ B. t. u., or 7,670 calories.

However, Table 6 (p. 28) shows that in 1916 these stills actually used an average of 0.011 barrel of fuel to 1 barrel of oil topped, which with 18° B. oil is 68,325 B. t. u., or 17,217.9 calories.

In addition some steam was used for agitation, which can be approximated as 320 boiler horsepower, or 0.575 boiler horsepower to a barrel of crude run which contains 19,250 British thermal units, making a total of 87,575 British thermal units consumed.[a]

The over-all efficiency of the crude batteries is therefore $\frac{30,402}{87,575}$, or 34.8 per cent.

HEAT EXCHANGERS.

Average daily temperature readings for November, 1916, on the fluids passing the heat exchangers are given in Table 5, with the computed rates of heat transmission in the apparatus.

TABLE 5.—*Average residuum and crude-oil temperatures in the heat exchangers of conventional crude stills during November, 1916.*

Average number of barrels of residuum each hour.	Average gravity of each barrel.		Average weight of each barrel.	Temperature of residuum.				Heating surface.	θ_m.	
				Ingoing.		Outgoing.				
	°B.	Specific gravity.		°F.	°C.	°F.	°C.	Square feet.	°F.	°C.
197.97	18	0.946	Pounds. 331.2	404.2	206.75	149.4	65.20	2,889.21	98.3	36.8

[a] The figures for steam consumption were furnished by Mr. C. Stamm, superintendent of the refinery.

TABLE 5.—*Average residuum and crude-oil temperatures in the heat exchangers of conventional crude stills during November, 1916*—Continued.

Average number of barrels of crude each hour.	Average gravity of each barrel.		Average weight of each barrel.	Temperature of crude.				Heat transmitted per square foot per hour per degree of mean temperature difference (K).	Heat apparently transmitted per square foot per hour per degree of mean temperature difference (K_1).
				Ingoing.		Outgoing.			
	°B.	Specific gravity.		°F.	°C.	°F.	°C.		
268.98	26	0.8974	*Pounds.* 314.4	87.4	30.75	258.6	125.85	*B. t. u.* 22.8	*B. t. u.* 23.8

Where $K=\frac{FS\,(T-t)}{H\,\theta_m}$=British thermal units transferred from residuum to crude oil per square foot per hour per degree of mean temperature difference.

$K_1=\frac{FS\,(T-t)}{H\,\theta_m}$=British thermal units apparently transferred from residuum to crude oil per square foot per hour per degree of mean temperature difference.

F=weight of fluid passing per hour.

S=specific heat of fluid (0.4 for residuum, 0.45 for crude).

H=heating surface of the exchanger computed as a mean between external and internal surfaces.

$$\theta_m=\frac{\theta_a-\theta_e}{\log_e \frac{\theta_a}{\theta_e}}=\text{mean temperature difference.}$$

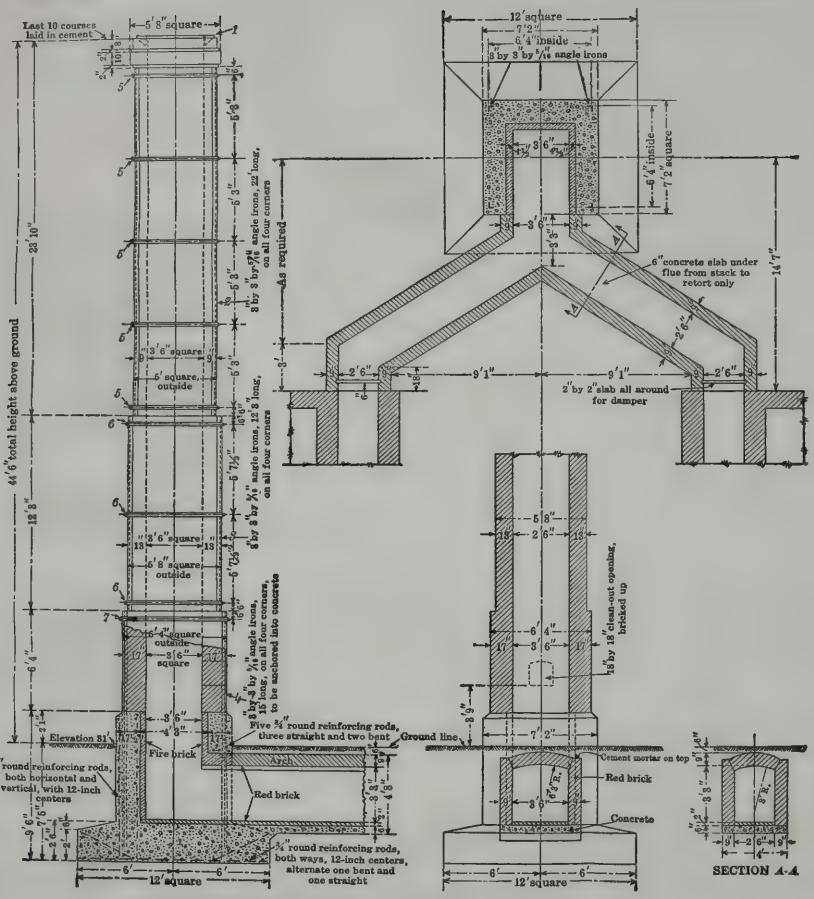
θ_a=difference between temperatures of fluids at beginning.

θ_e=difference between temperatures of fluids at end.

It will be noted that the flue-gas analyses show the results of normal operation of the crude stills using 165 to 191 per cent excess air for combustion, which corresponds to a fuel loss of 18 to 20 per cent. By lowering the dampers this loss could be reduceed to 10 per cent, and, undoubtedly, could be reduced still further.

Attention is called to the stack-draft data recorded in Table 4 (p. 12). The draft was greatly in excess of what should normally be required in the operation of the plant. Designers of oil-burning apparatus have been greatly influenced by the present designs of coal-burning equipment, and little dependable information has been compiled regarding correct design for oil-burning equipment. Results show conclusively, however, that oil fuel requires a relatively slight draft for proper combustion, and that the quantity of excess air can be reduced considerably.

The setting for crude stills does not readily adapt itself to an arrangement permitting any considerable reduction of stack-gas temperatures. However, topping plants can be so constructed as to reduce these temperatures decidedly. In fact, the stack-gas temperatures may be made to approach the temperature of the entering oil by making the gases flow counter to the oil. In the topper designed by Bell, stack temperatures of 385° F. have been attained



BRICK STACK AND FLUES, BELL TOPPING RETORTS, AVON REFINERY.

by the use of a prewarming coil placed in the flue. A reduction of 200° F. in the temperature of flue gases under average conditions corresponds to a 10 to 15 per cent saving in fuel.

Although perfect combustion practically can not be obtained when only the amount of air theoretically required is used, the excess quantity should not exceed 50 per cent with an oil fuel and a correctly designed furnace.

These batteries are constructed to permit preheating the air used for combustion, though no advantage is taken of this feature. If the air used were heated 100° F. by heat otherwise wasted in its travel around the air space of the batteries, the saving in fuel would be more than 5 per cent.

Briefly, the figures given show some of the more important fuel losses that might be corrected but are overlooked in the operation of many plants. Attending to these losses would materially increase the over-all efficiency.

The importance of frequent analysis of flue gases in oil-burning apparatus can not be too strongly emphasized.

POSSIBLE CHANGES AND IMPROVEMENTS.

With the method used of heating in fractions, it would seem that the fractions thus obtained should be fractionally cooled by the installation of dephlegmators on each vapor line, and the heavier distillates separated in the first running. The vapors coming from each dephlegmator could then each constitute a distinct product requiring only slight treatment in the steam stills. The result would be a saving in fuel and a reduction in plant area, as the steam-still capacity could be reduced. The capacity of the crude batteries would not be affected.

The crude settings should incorporate some type of prewarmer to utilize the waste flue gases and reduce the stack temperature. It would be possible to pass these gases on their way to the stack through a tubular boiler containing the entering oil from the heat exchangers, thus materially reducing the temperature of the flue gases. The heat recovered by the oil would probably obviate the necessity of firing the first still, which could then be used as a separating chamber only for the vapors evolved.

The rate of heat transfer in the exchangers is unusually high and justifies the effort to embody correct engineering principles. The velocities of the fluid are high, and the cross-sectional areas of the oil spaces small, both conditions being necessary for rapid heat exchange. By causing the entering oil to flow through the 2-inch pipes, all heat acquired by it is retained for useful duty, whereas the heat radiated to the air by the residuum probably does not lessen appreciably the amount transferred to the oil, and does assist in cooling the residue before it passes to storage.

MISCELLANEOUS TOPPING PLANTS.

PLANT CONSTRUCTED AFTER DESIGN OF A. F. L. BELL.

GENERAL DESCRIPTION.

A topping plant of the Bell design has been running successfully for several years at Gaviota, Cal. In 1911–12 two batteries of such plants were constructed for the large refinery at Avon, Cal., already mentioned. They are the most recent installations of this type, and therefore description of the type is confined to the Avon plant.

The refinery handles about 20,000 barrels of 26° B. oil (specific gravity, 0.8974) daily, which is supplied by two 8-inch oil lines from the Fresno and Kern County fields. The toppers normally handle 3,500 barrels each, the remainder being topped in two batteries of conventional stills, described elsewhere.

The topping plant in general consists of two batteries of retorts each containing several banks of 4-inch pipes arranged as a continuous coil for the flow of the oil under fire. Each battery feeds a separating tower, the vapors from each tower in turn being led to two box condensers connected in parallel. In addition, each battery is provided with a heat exchanger for the exchange of heat between ingoing oil and outgoing residuum.

The first-run distillates are rerun through four combination steam and fire stills and two steam stills, each of which is provided with condensers of the same type and size as those used on the crude set.

Each still is equipped with a vapor-separating tower similar to those of the topping set. The interior construction, however, differs, and is described in the text following.

DETAILED DESCRIPTION OF APPARATUS.

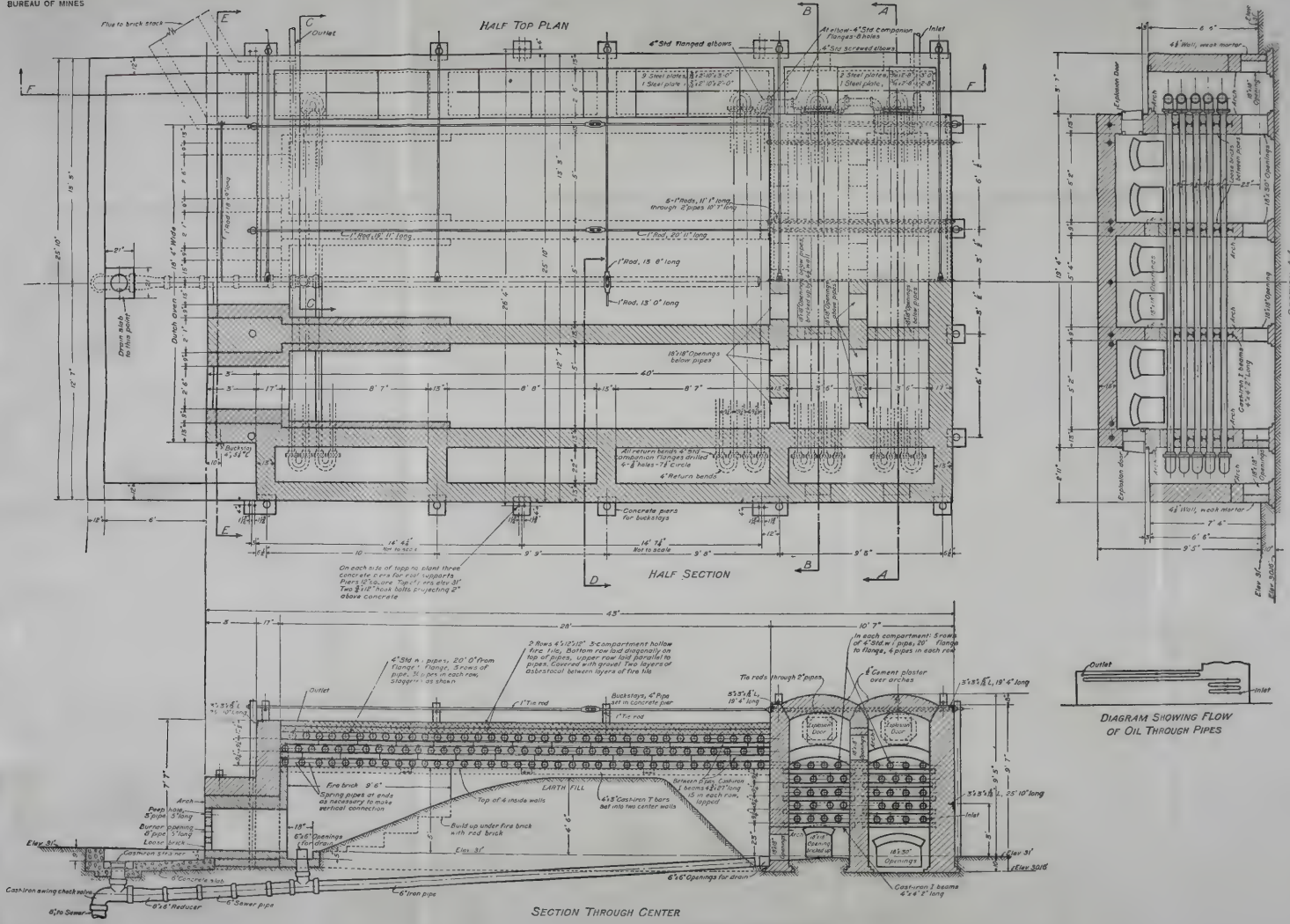
RETORTS.

Plates IV, V, VI, and VII show the construction of these retorts.

Data on apparatus shown in Plate IV.

Part No.	Number required.	Name of part.	Kind of material.
1	1	Chimney top	Cast iron.
2	4	3 by 3 by $\frac{5}{16}$ inch angle iron, 22 feet long	Steel.
3	4	3 by 3 by $\frac{5}{16}$ inch angle iron, 12 feet 3 inches long	Do.
4	4	3 by 3 by $\frac{5}{16}$ inch angle iron, 15 feet long	Do.
5	20	2 by $\frac{3}{8}$ inch bar, 4 feet 10 inches long	Do.
6	12	2 by $\frac{3}{8}$ inch bar, 5 feet 6 inches long	Do.
7	4	2 by $\frac{3}{8}$ inch bar, 6 feet 2 inches long	Do.

Each retort battery consists of three parallel adjacent furnaces 5 feet wide by 28 feet long, constructed of 13-inch red-brick walls 5 feet high. These walls are faced with fire brick for 10 feet from the front end of the furnaces. The front wall of the battery is 7 feet 7 inches high and 17 inches thick, of red brick faced with fire brick to the top of the division walls between the furnaces. The rear wall is 8 feet 9 inches high and 13 inches thick, of red brick. Three rows



PLAN AND SECTION, BELL TOPPING RETORTS, AVON REFINERY.

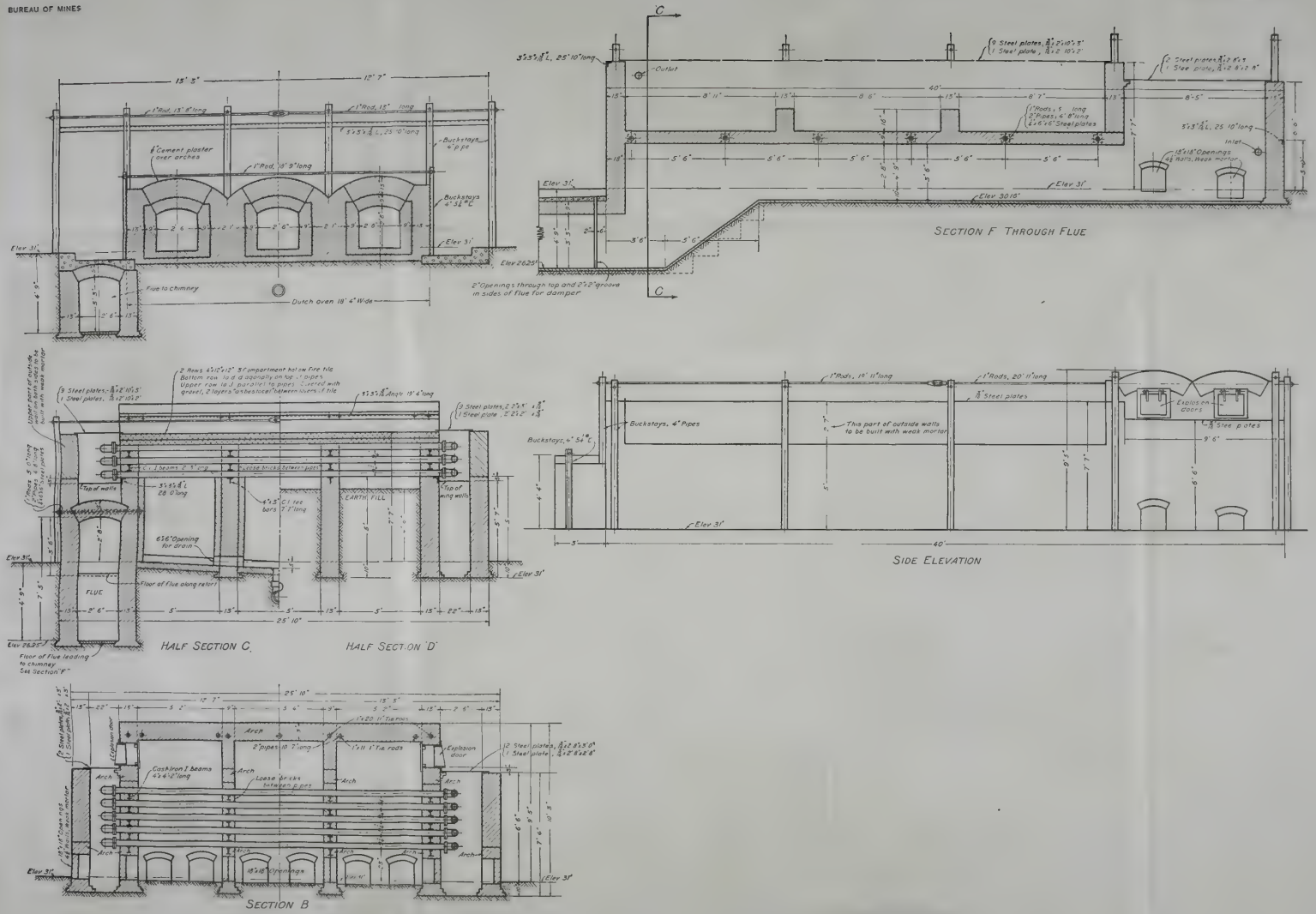
each of 36 4-inch wrought-iron pipes 20 feet long are placed across the furnaces at right angles to the direction of the fires. The first row rests on the side and division walls of the furnaces, and the other two are separated and supported by four ⅞-inch I beams 27 inches long, lapped and placed directly over each wall. The top row of pipes carries the roof consisting of two layers of 4 by 12 by 12 inch hollow tile, with asbestos fiber between the tiling and a loose gravel covering over the tile. The pipes in each row are connected end to end by 4-inch flanged return bends, forming a continuous coil for the flow of the oil.

The front wall of the battery surmounts three small Dutch ovens, each opening into a furnace. Their purpose is to enlarge the combustion chambers and prevent the flames from impinging directly on the coils. The oil used for fuel is atomized by steam through fish-tail burners, proper feed being adjusted by valves situated at the front of the furnaces. Within each furnace an earthen fill 4 feet 6 inches high is provided, sloping from the front of the furnace to its maximum height at the middle, where it is level for several feet, abruptly sloping to the exit for the gases at the rear of the furnace. The fill forces combustion gases to flow around the pipes in leaving the furnaces.

Two openings, 18 by 18 inches, from each furnace are provided in the rear wall near the floor. A two-compartment flue is placed parallel to this rear wall, comprising 2 brick walls 7 feet 9 inches high, and 3 feet 6 inches apart, covered by brick arches. Five rows of four 4-inch wrought-iron pipes 20 feet long are supported in each compartment by 4-inch I beams embedded in the walls. They are connected end to end by flanged return bends forming a continuous prewarming coil for the oil entering the furnaces. Six openings, 18 by 18 inches, are provided in the division wall between the two compartments near the top for the passage of the flue gases, which finally leave the coils by an opening, 18 by 30 inches, near the floor at one end of the outside compartment. It will be noted that the return bends project just beyond the main outside walls of the battery. To prevent radiation losses light auxiliary walls are constructed paralleling these outside walls about 2 feet from them. The space between these walls is roofed with sheet iron, and on one side the space is utilized as a flue for the escape of the gases. A damper is provided on this flue just outside the battery, the flue being extended a short distance underground to a rectangular brick stack serving both batteries. Plate IV shows this stack. The entire battery is suitably buckstayed, and a low steel structure supports a galvanized roof for its protection from the weather. (See Pls. V, VI, and VII.) The heaters in course of construction are shown on Plate VIII and a front view of the completed unit is shown in Plate IX, A.

List of materials for topping plant shown in Plate VI.

Common red brick	65,000
Fire brick	3,400
Arch fire brick, 2½ by 2 by 4½ by 9 inches	700
Three-compartment fireproof tile, 4 by 12 by 12 inches	1,220
Pipe buckstays, 4 inches in diameter and 11 feet long	18
4-inch 5¼-pound channels 6 feet long, for buckstays of Dutch oven	2
1-inch rods 19 feet 11 inches long, right-hand threads on both ends, for longitudinal ties	4
1-inch rods 20 feet 11 inches long, right-hand thread on one end, left-hand thread on other end, for longitudinal ties	4
1-inch rods 13 feet long, right-hand thread on both ends, for transverse ties	5
1-inch rods 13 feet 8 inches long, right-hand thread on one end, left-hand thread on other end, for transverse ties	5
1-inch rod 18 feet 9 inches long, right-hand thread on each end, for tie for Dutch oven	1
1-inch rods 11 feet 1 inch long, right-hand threads on each end, for rear-end ties	5
1-inch rods 5 feet long, two right-hand threads, for ties over flue	6
2-inch pipes 10 feet 7 inches long, for rear-end ties	9
2-inch pipes 4 feet 8 inches long, for tie rods over flue	6
¼ by 6 by 6 inch plates with 1⅛-inch hole in center, for flue ties	12
1-inch turnbuckles with right-hand and left-hand threads	9
3 by 3 by $\frac{5}{16}$ inch angle irons 25 feet 10 inches long, for front and rear walls	2
3 by 3 by $\frac{5}{16}$ inch angle irons 19 feet 4 inches long, for rear compartments	2
3 by 3 by $\frac{5}{16}$ inch angle irons 28 feet long, for longitudinal walls	2
4 by 3 inch cast-iron tee bars 7 feet 7 inches long	8
4¾-inch cast-iron I beams 2 feet 3 inches long	120
4-inch cast-iron I beams 4 feet 2 inches long	40
Explosion doors, complete	4
3-inch pipes 5 feet long for peep holes in fire fronts	3
8-inch pipes 5 feet long for burner openings	3
Steel plates $\frac{3}{16}$ inch by 2 feet 10 inches by 3 feet	9
Steel plate $\frac{3}{16}$ inch by 2 feet 10 inches by 2 feet	1
Steel plates $\frac{3}{16}$ inch by 2 feet 8 inches by 3 feet	2
Steel plate $\frac{3}{16}$ inch by 2 feet 8 inches by 2 feet 8 inches	1
Steel plates $\frac{3}{16}$ inch by 2 feet 2 inches by 3 feet	9
Steel plates $\frac{3}{16}$ inch by 2 feet by 3 feet	2
Steel plate $\frac{3}{16}$ inch by 2 feet 2 inches by 2 feet	1
Steel plate $\frac{3}{16}$ inch by 2 feet by 2 feet 8 inches	1
1-inch hexagonal nuts, tapped	42
Cast-iron damper	1
4-inch standard pipes 20 feet long, to be made up	149
4-inch flanges, return bends	141
4-inch standard flanged elbows	6
4-inch standard screwed elbows	6
4 by 9 inch companion flanges drilled with four ⅞-inch holes on 7½-inch circle, for return bends	282
4 by 9 inch companion flanges, with standard eight-hole drilling, for flanged elbows	12
4 by 9 by $\frac{1}{16}$-inch asbestos fiber gaskets	294
¾ by 3-inch bolts with hexagonal nuts, for return bends	1,128
⅝ by 2¾ inch bolts, with hexagonal nuts, for elbows	96



SECTIONS OF BELL TOPPING RETORT, AVON REFINERY. FOR LIST OF MATERIALS SEE TABLE ON PAGE 18.

SEPARATING TOWERS.

Each separating tower (Pl. X, p. 26) consists of a vertical cylindrical shell 6 feet in diameter and 50 feet high. The shell is constructed in sections of rolled-steel plates riveted together and provided with a convex head riveted to the top plate. A suitably rolled angle shape is riveted to the edge of the bottom plate, forming a base to which to anchor the tower to its foundation. About 4 feet up from this angle a convex head, fitted with a 6-inch flange for the residuum draw off, is riveted to the inside of the shell. The space between the top and the bottom heads forms the separating chamber for the oil and vapors. Two 24-inch manholes for the inspection of the interior are provided, one near the top and the other about 20 feet from the bottom.

A 12-inch flange is riveted to the shell 14 inches from the top for the vapor take-off line, and a 4-inch flange is provided 44 inches from the top for the inlet of hot oil.

Within the shell a vertical partition divides the tower into two equal compartments from a point just above the oil inlet to within 20 feet 5½ inches of the bottom. The top of the compartment adjacent to the oil inlet is covered with a solid plate, and at approximately equal intervals five horizontal perforated baffles are set within this compartment. Oil and vapors enter at the top and the oil is finely divided in falling to the residuum reservoir at the bottom. The vapors are forced to pass down through the baffle compartment and then upward through the other compartment to the 12-inch outlet near the top. An asbestos covering is provided over the entire exterior and protected by galvanized-iron sheets placed over it so that the heat loss from radiation is materially reduced. Plates IX (p. 24), and X (p. 26), show this tower.

CONDENSER.

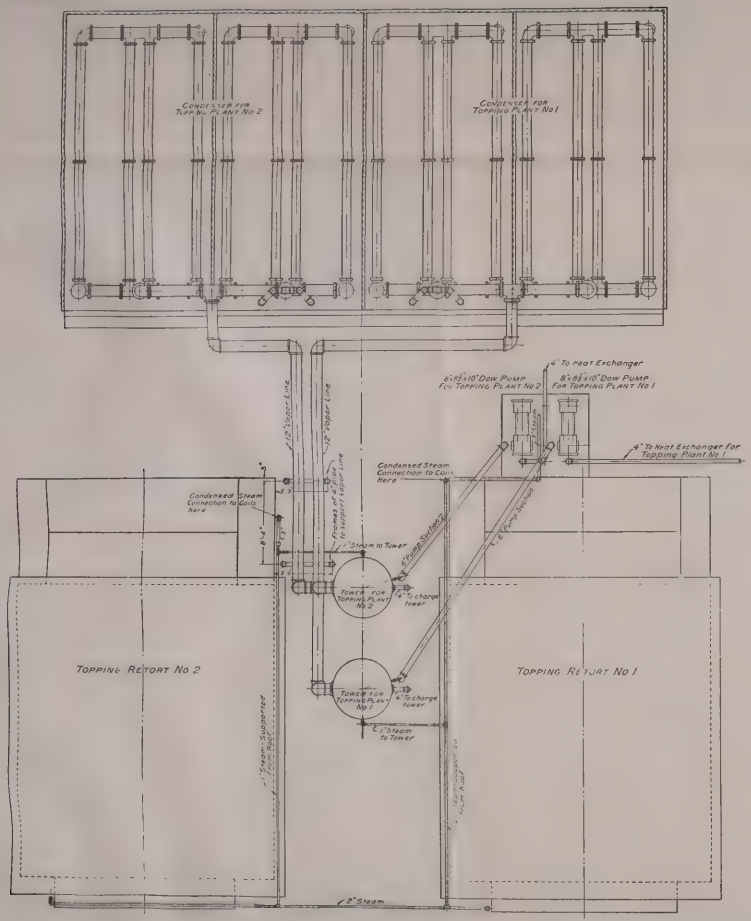
The condenser consists of a rectangular steel box 30 feet long, 10 feet 9 inches high, and 15 feet wide, made of steel plates riveted together and reinforced with angle irons and sag rods. Within the box are placed seven horizontal rows of cast-iron pipes of diminishing sizes (Pl. XI, p. 28). The pipes are connected end to end by cast-iron return bands, and arranged so that the vapors and distillates pass back and forth and downwards through each row of pipes to the distillate outlet near the bottom. The bottom bank of tubes is given a 3-inch fall to the outlet. Water is discharged into the box near the bottom from an overshot pipe, and leaves at the top by overflowing one edge into a collecting trough supported by brackets riveted to the condenser.

The 12-inch vapor line from the separating tower supplies a 12-inch header connected to two condenser boxes. On this header a pressure and vacuum relief valve is set and regulated to suit normal operating conditions.

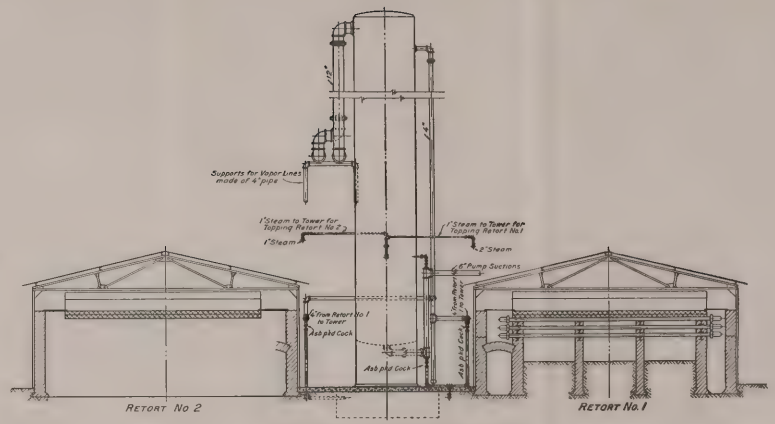
List of materials for equipment shown in Plate XI.

Part No.	Part.	Material.	Number required for one two-compartment condenser for steam stills.	Number required for two four-compartment condensers for crude oil stills.
1	Condenser box	Steel	a 1	b 2
2	12-inch manifold	Cast iron	2	8
3	do	do	2	8
4	10-inch by 8-inch return bend	do	2	8
5	8-inch by 5-inch return bend	do	2	8
6	6-inch by 4-inch return bend	do	2	8
7	10-inch return bend	do	6	24
8	8-inch return bend	do	2	8
9	6-inch return bend	do	10	40
10	4-inch return bend	do	46	184
11	10 by 10 by 12-inch side outlet elbow	do	2	8
12	4-inch flanged pipe, 12 feet long	do	104	416
13	4-inch flanged pipe, 2 feet 11 inches long	do	2	8
14	4-inch flanged pipe, 2 feet long	do	2	8
15	6-inch flanged pipe, 12 feet long	do	40	160
16	6-inch flanged pipe, 4 feet long	do	16	16
17	6-inch flanged pipe, 4 feet 8 inches long	do	17	17
18	8-inch flanged pipe, 12 feet long	do	16	64
19	8-inch flanged pipe, 3 feet 9 inches long	do	4	16
20	10-inch flanged pipe, 12 feet long	do	40	160
21	10-inch flanged pipe, 20 feet long	do	4	16
22	12-inch flanged pipe, 3 feet 2 inches long	do	8	32
23	4-inch standard flanged elbow	do	8	32
24	6-inch standard flanged elbow	do	16	62
25	8-inch standard flanged elbow	do	8	34
26	10-inch standard flanged elbow	do	10	40
27	12 by 10-inch standard flanged elbow	do	6	16
28	12 by 12 by 10-inch side outlet elbow	do	0	8
29	4-inch flanged pipe, 2 feet 3 inches long	do	2	8
	4 by 9-inch standard flange	do	2	8
	$\frac{7}{8}$ by 4-inch square-head machine bolt with hexagonal nut.	Steel	24	96
	$\frac{7}{8}$ by $3\frac{1}{2}$-inch square-head machine bolt with hexagonal nut.	do	768	3,072
	$\frac{7}{8}$ by $2\frac{3}{4}$-inch square-head machine bolt with hexagonal nut.	do	240	960
	$\frac{3}{4}$ by $3\frac{1}{4}$-inch square-head machine bolt with hexagonal nut.	do	200	800
	$\frac{3}{4}$ by 3-inch square-head machine bolt with hexagonal nut.	do	1,120	4,480
	$\frac{3}{4}$ by $2\frac{3}{4}$-inch square-head machine bolt with hexagonal nut.	do	216	864
	12 by 19-inch gasket	$\frac{1}{16}$-inch asbestos, soaked in glycerin.	16	64
	10 by 16-inch gaskets	do	70	280
	8 by $13\frac{1}{2}$-inch gaskets	do	32	128
	6 by 11-inch gaskets	do	76	304
	4 by 9-inch gaskets	do	169	676

a Two-compartment. b Four-compartment. c All bolts galvanized.



Upper Plan



Cross Section Through Topping Retorts

GENERAL ARRANGEMENT AND ELEVATION, BELL TOPPING PLANT, AVON REFINERY.

Drilling for flanges.

Diameter of bore hole.	Diameter of flange.	Number of bolts.	Diameter of bolt holes.	Diameter of B. C.
Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
4	9	4	$\frac{7}{8}$	$7\frac{1}{2}$
6	12	8	$\frac{7}{8}$	$9\frac{1}{2}$
8	$13\frac{1}{2}$	8	$\frac{7}{8}$	$11\frac{3}{4}$
10	16	12	1	$14\frac{1}{4}$
12	19	12	1	17

SPECIFICATIONS.

MATERIAL.—All pipe and fittings shall be made of cast iron, to be of tough gray metal, close, even grained, uniform in quality and soft enough to permit drilling and cutting and to be capable of showing indentations from the sharp blow of a hammer without flaking, showing a tensile strength of not less than 20,000 pounds per square inch without breaking on a turned specimen 1 inch in diameter. All castings are to be free from cracks, air holes, sand holes, coal shuts and all other imperfections and to have a smooth inner and outer surface. No plugging of holes or flaws will be allowed.

CHAPLETS.—All chaplets supporting cores are to be of cast iron.

WORKMANSHIP.—Variations in thickness shall not be more than one-fourth of an inch less than specified. All pipe and fittings are to be carefully cooled so as to avoid unequal contraction or chilling.

FLANGES.—Flanges are to be faced true and smooth and drilled to receive bolts of the size specified. All drilling is to be done with proper templates, holes are to straddle center lines of fittings, and holes in all pipe flanges must be in alignment.

INSPECTION.—All pipe and fittings are to be thoroughly cleaned and subject to inspection. All pipe and fittings are to be delivered sound and in full accord with these specifications, and any pipe found defective shall be rejected and replaced by the contractor free of charge.

TEST.—Pipe is to be capable of withstanding an internal pressure of not less than 50 pounds per square inch without sign of sweating or other leaks.

HEAT EXCHANGER.

The heat exchanger comprises 20 lengths of standard 10-inch wrought-iron pipe, each 48 feet long arranged in 4 rows of 5 lengths to each row (figure 1 and Plate XII). Each pipe is fitted with flanges, and special cast-iron manifolds join the pipes in each row to form a continuous path for the oil passing through them. Within each 10-inch pipe five 2-inch pipes are placed and joined together within the manifolds by elbows and nipples on one end and tapped plates on the other to form a continuous coil. Cold oil enters the heat exchanger at the bottom row on one side, flowing back and forth and upward through the 2-inch tubes countercurrent to the hot residuum surrounding them. Cast-iron tees with reducers are provided at the inlet and outlet of the apparatus, the 2-inch tubes being screwed into a flat plate between reducer and tee. Separators are placed in each 10-inch pipe to hold the small pipes in position.

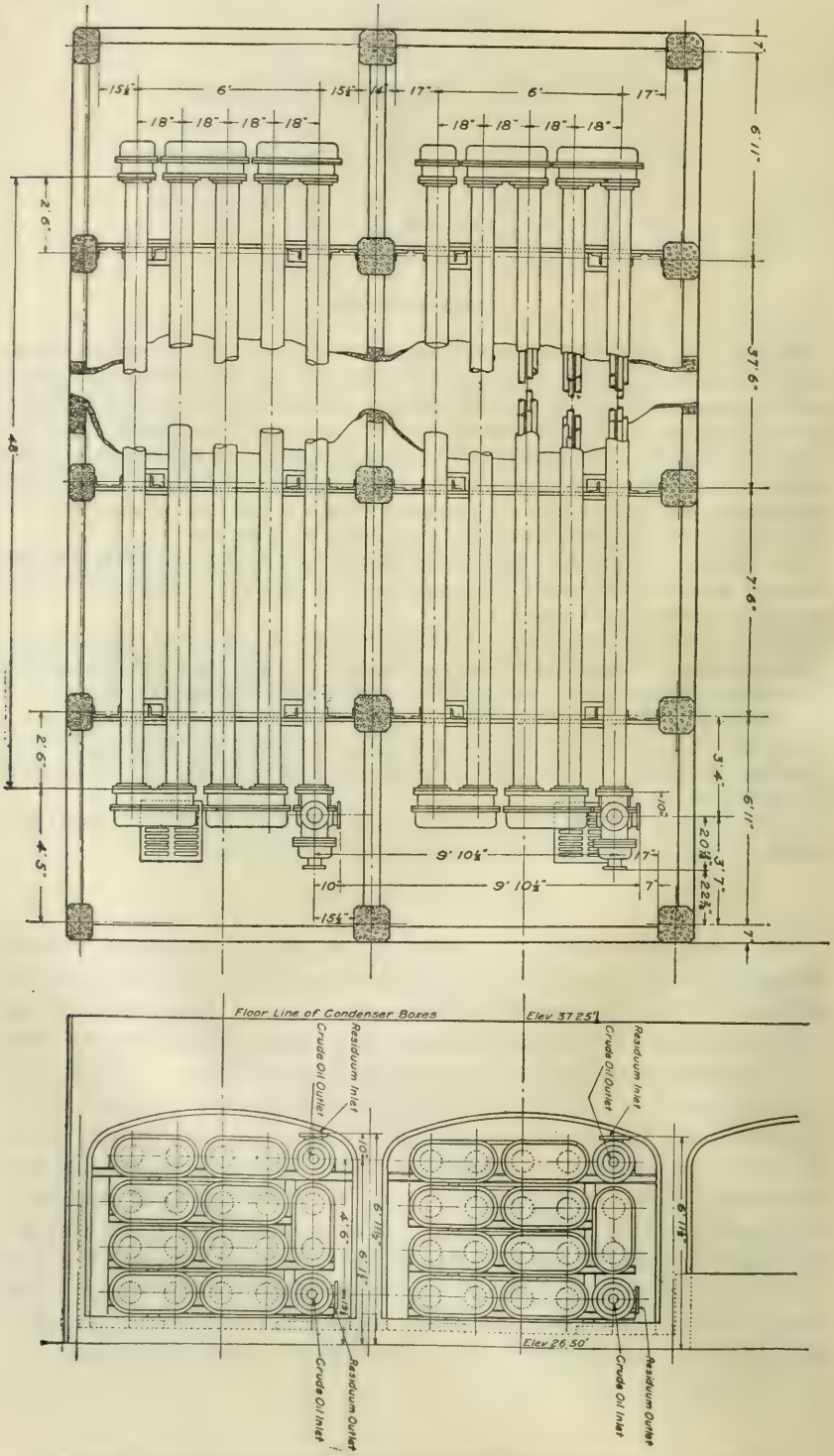


FIGURE 1.—General arrangement of heat exchanger in Bell topping plant, Avon refinery.

A. RIGHT-HAND VIEW OF BELL RETORTS DURING CONSTRUCTION. NOTE PREWARMING COIL.

B. FRONT AND LEFT-HAND VIEW OF BELL TOPPING RETORT DURING CONSTRUCTION.

C. FRONT VIEW OF BELL RETORTS, SHOWING DUTCH OVENS.

STEAM STILL.

Each steam still (Pls. XIII and XIV, pp. 32 and 34) consists of a horizontal cylinder 10 feet in diameter and 40 feet in extreme length, fitted with round heads at each end. The top of the still is fitted with a 20-inch manhole for inspection of the interior, a combination vacuum and pressure relief valve, a 12-inch vapor outlet, and several flanges for steam connections. The bottom is fitted with several flanges for draw-off lines, and the 6-inch charging line is flanged to one side near the top.

Within the still four perforated 2-inch steam lines are placed near the bottom for steam agitation, and above each one is fitted a 2-inch steam heating coil draining to flanges on the still side. Vertical baffle plates are set across the still between each coil to permit fractional distillation of the distillate within the still. The feature is not utilized in the method of operation in use. A 3-inch tile covering supported by an angle placed horizontally around the middle of the still protects the upper half from heat losses and prevents cracking of the products. Plate IX, *B* (p. 24), shows a general view of the stills and the separating tower.

SEPARATING TOWER.

The general construction of the separating tower (Pl. XV) is similar to that of the tower used with the crude set. On the exterior are two 12-inch vapor outlets, one 14 inches and the other 24 feet 8 inches below the top. A 12-inch vapor inlet is placed 2 feet 6 inches below the lower outlet. The 4-inch distillate charging line enters the tower 14 inches below the top vapor outlet. About 2 feet below the vapor inlet a horizontal bottom is riveted to the inside of the shell which is fitted with a 6-inch flange for the connection to the still. Distillates dropping to the bottom of the tower pass to the still through this flange. Within the shell a horizontal grate is placed approximately 24 feet from the top and supports hollow tiling which is placed on end and completely fills the upper part of the tower. Deflector plates at intervals along the inside of the shell force the entering distillate through the tiling on its way to the still. The shell is insulated with asbestos covering, protected by galvanized sheet iron.

CONDENSERS AND COOLERS.

The condensers are like those described on page 19. In addition five coolers are provided to cool the steam-still and the combination-still bottoms. Three of them consist of two horizontal rows each of eight 4-inch cast-iron pipes 24 feet long, and the other two are composed of two horizontal rows each of eight 4-inch cast-iron pipes 36 feet long, each set of cooler pipes being connected by return bends to form a continuous coil. These coils are submerged in shallow concrete tanks below the condensers.

List of materials for heat exchanger shown in Plate XII.

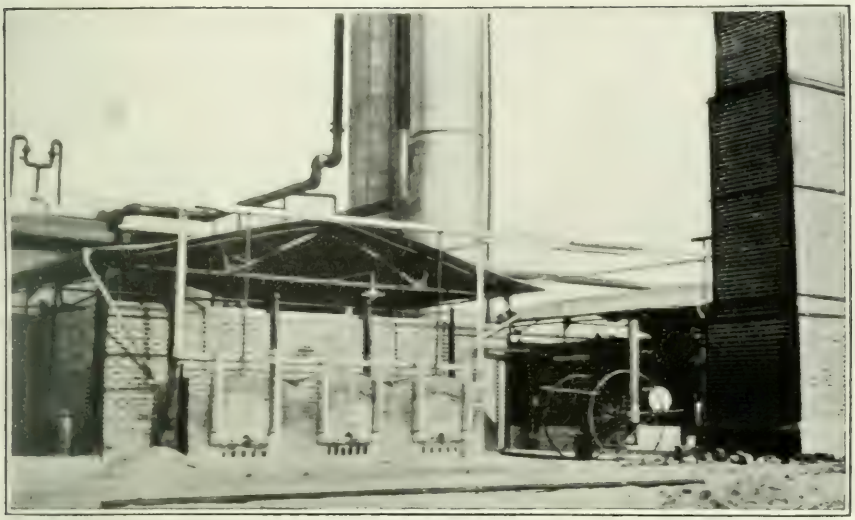
[Numbers are same as those on Plate XII.]

Part No.	Part.	Material.	Number required.
1	Plate	Cast iron	16
2	do	do	2
3	Reducer	do	2
4	Tee	do	2
5	Cover	do	19
6	Cover plate	do	38
7	Box, open end	do	10
8	Box, closed end	do	9
9	Separator	Cast brass	40
10	Strap	Wrought iron	80
11	Standard 10-inch flange	Cast iron	40
12	Standard 2-inch elbow	Malleable iron	60
13	Standard 2-inch street	do	40
14	Standard 2-inch union	do	50
16	Standard 2-inch pipe nipple, 6 inches long	Black iron	20
17	Standard 2-inch pipe nipple, 13 inches long	do	20
18	Standard 2-inch pipe nipple, 9 inches long	do	10
19	Standard 2-inch pipe nipple, 10 inches long	do	10
20	Standard 2-inch pipe nipple, cut to lengths shown.	do	100
21	Standard 10-inch pipe, cut to lengths shown.	32.5-pound black iron.	20
22	Gasket, 17-inch	Asbestos fiber	4
23	Gasket, 16-inch	do	40
24	Gasket, 12-inch	do	18
25	Gasket, 8¾-inch	do	38
26	Gasket, 17½ by 35½ inches	do	19
27	Cap screws, ⅝ by 1½ inches, hexagonal head		304
28	⅝ by ⅞ inch square-headed machined bolts, with hexagonal nuts.	Steel	494
29	⅞ by 3¼ inch studs with 1¼-inch thread	do	144
30	⅞ by 3¼ inch studs with 1 and 1½ inch thread	do	480
31	⅞ by 3½ inch square-headed machined bolts, with hexagonal nuts.	do	24
32	¾ by 4 inch square-headed machine bolts	do	24

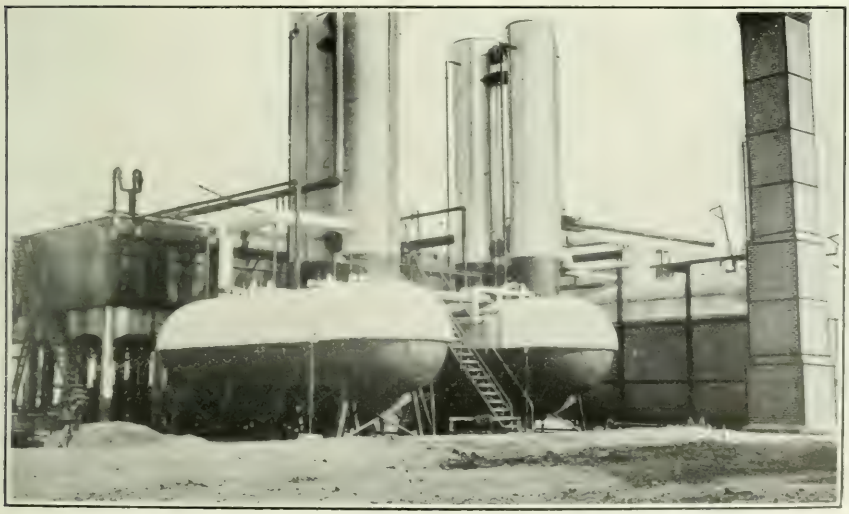
Data on parts shown in Plate XIII.

[Numbers are same as those on Plate XIII.]

Part No.	Part.	Material.	Number required.
1	Header	Cast iron	4
2	do	do	4
3	do	do	4
4	4 by 3 inch bushing	do	1
5	3-inch coupling	Wrought iron	4
6	2-inch coupling	do	4
7	3-inch elbow	Malleable iron	10
8	2-inch elbow	do	14
9	3-inch railroad union	do	4
10	2-inch railroad union	do	128
11	1½-inch plugs	Cast iron	24
12	2-inch, 45° elbow	Malleable iron	4
13	2-inch cap	do	24
14	Return bend	do	120



A. FRONT VIEW OF COMPLETED UNITS, BELL TOPPING RETORTS. NOTE SEPARATING TOWERS AND BRICK STACK SERVING TWO UNITS.



B. STEAM STILLS AND SEPARATING TOWER, BELL TOPPING PLANT.

COMBINATION FIRE AND STEAM STILLS.

Each combination still (Pl. XVI, p. 38) consists of a horizontal shell 12 feet in diameter by 48 feet in length, with convex heads. They are placed over a brick setting, as shown in Plates I and II (pp. 6, 8), and are directly fired in addition to having steam coils within the shell.

The still is equipped with a dome on top, a manhole at one end, and several flanges for steam connections and charging lines. The draw off is placed at one end of the bottom. Within the still three perforated 2-inch pipes are placed on the bottom for steam agitation, and above them are suspended four coils of 3-inch steam pipes, each consisting of five horizontal rows of four pipes each 19 feet 9 inches long, connected end to end by return bends. The vacuum and pressure relief valves are connected to the dome and for convenience are placed adjacent to the condensers.

The separating tower serving each still is like those used on the steam still, as are also the condensers and coolers. Two square brick stacks serve two stills each by means of underground flues (see Pl. IV, p. 14). Steam used in the stills, pumps, burners, etc., is supplied by a battery of four 150-horsepower, two 175-horsepower, and two 200-horsepower Stirling boilers grouped in the main boiler house.

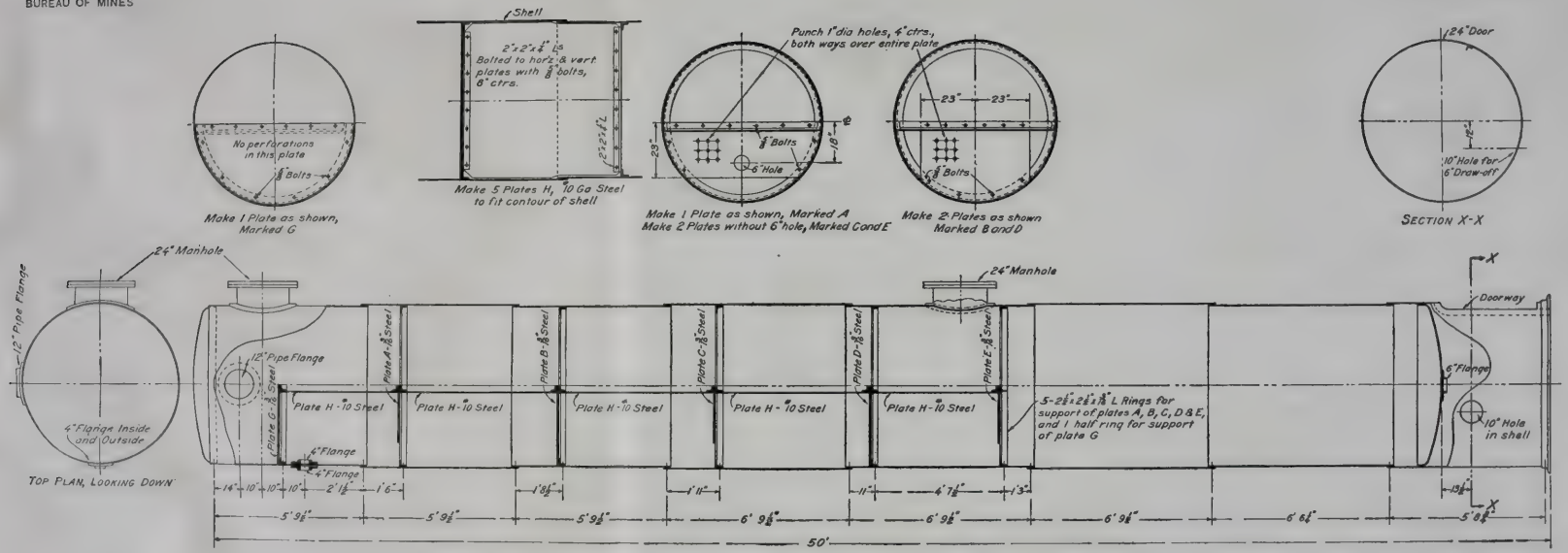
OPERATION.

The course of the oil through each battery is as follows: Crude oil entering the plant passes through a horizontal cylindrical steel tank placed in the line. The increased cross-sectional area diminishes the velocity of the entering fluid, and water carried in the oil settles out. From this tank the oil passes through a Dow duplex pump 8 by 8½ by 10 inches and is forced through the tubes of the heat exchanger, entering at the bottom and leaving at the top. Flowing counter-current to it the outgoing residuum parts with considerable heat, and the entering oil thus partly warmed enters the prewarming coil in the rear of the retort battery. The oil passes back and forth and upward through this coil heated by escaping flue gases and then enters the bottom row of pipes in the main coil. This coil is directly fired and the oil travels back and forth successively through each row of pipes, leaving at the forward end of the top row through a 4-inch pipe to enter the top of the separating tower. This pipe is equipped with a regulating valve which insures a steadiness of pressure on the coils. The toppers operate at an average temperature of 435° to 450° F. (223.8° to 232.2° C) and produce a residual oil which flashes in an open cup at about 150° F. (65.5° C.).

The heated oil, when sprayed down through this tower, gives off the vapors accompanying it, which pass out of the baffled compartment and upward through the other compartment to the vapor take-off near the top. The residual oil collecting at the bottom feeds a Dow duplex pump, 8 by 8½ by 10 inches, which forces it through the jacket of the exchanger to storage. The piping to this pump is arranged so that a constant depth of residuum is maintained in the lower part of the tower. This oil can be brought to any desired specification by controlling the rate of fire and feed at the retort. Vapors leave the tower near the top through a 12-inch line connected to two condenser boxes. Flowing downward through the coil contained in the box, they are condensed and cooled by the surrounding water, and the condensate gravitates through the tail house to water-seal run-down tanks. All run-down lines to the tail house are equipped with automatic water traps made of vertical stands of 10-inch pipe having a water outlet adjusted to balance the column of water with a column of distillate. Cooling water for the condensers is pumped from the bay and returned through the sewer after use in various places about the plant for flushing drains, pipe roads, etc. The pump is placed about 150 feet from the plant and the entire arrangement permits great flexibility when the retorts are operated at forced capacity. Products can always be satisfactorily cooled.

Data on material required for apparatus shown in Plate XVI.

Forty-eight wrought-iron pipe supports (Nos. *1* to *10*, Pl XVI).
About 125 feet of ½-inch round rod (No. *11*, Pl. XVI) for pipe supports.
Two ½-inch U bends (No. *12*, Pl. XVI) with hexagonal nuts and cut washers for 3-inch pipe supports.
Two ⅝-inch U bends (No. *13*, Pl XVI) with hexagonal nuts and cut washers for 4-inch pipe supports.
One 6-inch to 3-inch bushing (No. *14*, Pl. XVI).
About 14 feet of 6-inch standard pipe.
About 6 feet of 4-inch standard pipe.
About 1,800 feet of 3-inch standard pipe.
About 125 feet of 2-inch standard pipe.
Two 6-inch standard elbows.
One 6-inch standard pipe sleeve.
One 4 by 4 by 6 inch standard tee.
Six 4 by 4 by 3 by 3 inch standard crosses.
Two 3 by 3 by 4 inch standard tees.
Forty-three 3-inch standard elbows.
Eighteen 3-inch standard tees.
Sixty-four 3-inch standard return bends.
Forty-one 3-inch standard Kewanee unions.
Four 2 by 2 by 3 inch tees.
Four 2-inch tees.
Twelve 2-inch standard caps.



CROSS SECTION OF SEPARATING TOWER, BELL TOPPING PLANT, AVON REFINERY.

RERUNNING PLANT.

All fractionation of the first-run distillate is accomplished in the steam stills or combination stills. They are operated semicontinuously and independently, the combination stills being served by one tower and two condensers each, whereas the steam stills are provided with only one condenser and one tower each.

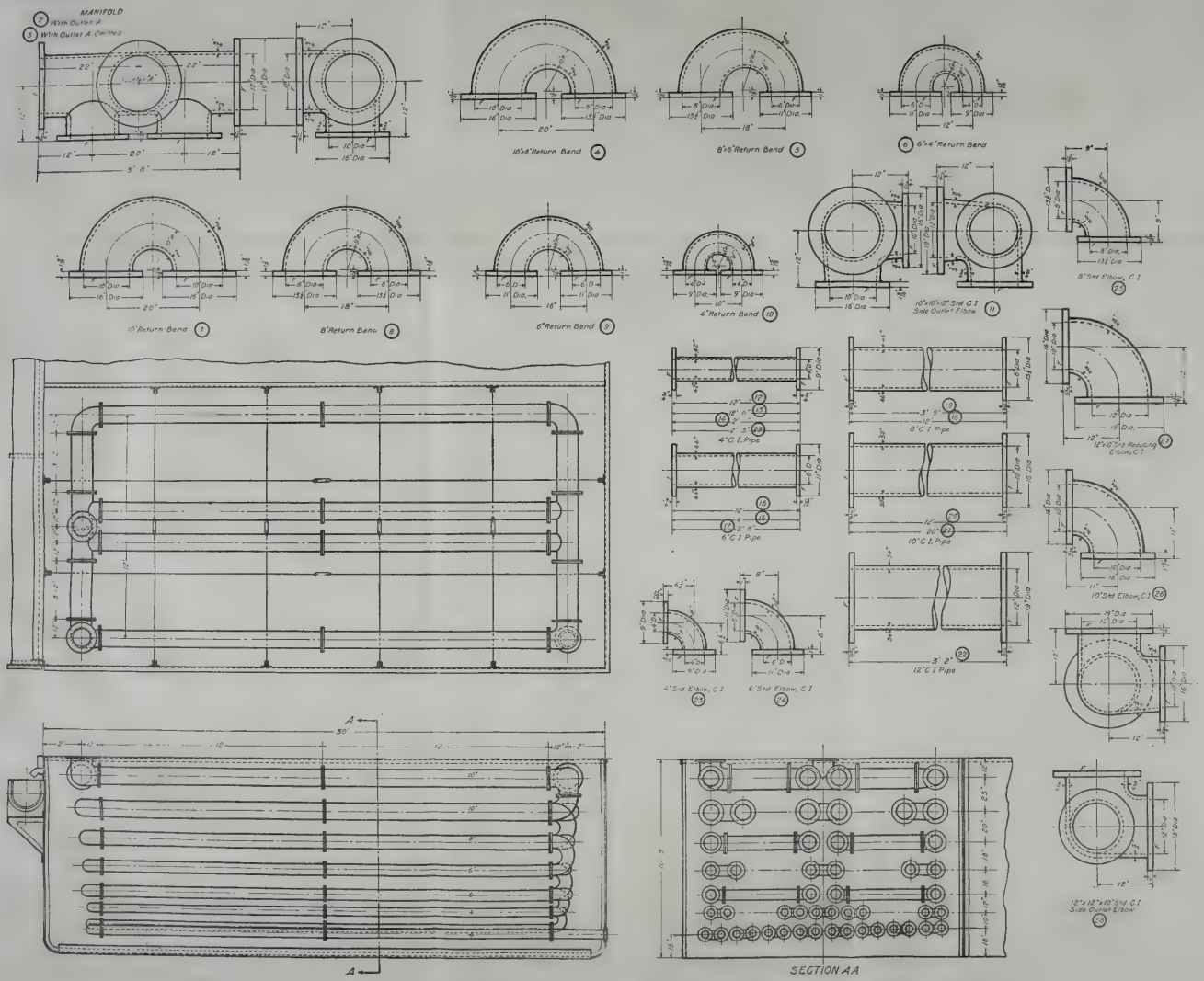
In operating the plant, each still is charged at night to about two-thirds its maximum capacity and distillation is commenced. As the operation proceeds, distillate is continuously charged through the tower to the still, replacing the evaporated part. The still is maintained at a constant temperature until it is full of distillate of a certain gravity, when charging through the tower is stopped and the contents reduced to a residual steam-still "bottoms" by gradually raising the temperature. At the end of a 24-hour period the still "bottoms" or residue is drawn off and the still recharged for the following day's run. Two objects are accomplished in this method of operation—the entering distillate is preheated in its course through the tower, and the vapors evolved in the still are subjected to a dephlegmating or cooling process in passing upwards through the distillate-cooled tiling. Only the lighter vapors pass off at the top, heavier fractions being condensed and returned to the still for reevaporation.

With the tower used on the combination still the lower vapor take-off is used to take off a heavy fraction without subjecting it to the dephlegmating action of the tower. Fractionation is controlled at the tail house by sampling the discharge from the run-down lines. By switching these lines to the various run-down tanks at proper intervals any number of fractions can be made, the only limit being the tank capacity available. However, market conditions and demands usually determine the number of products manufactured. The Avon refinery makes gasoline, engine distillate, stove oil, and still "bottoms."

Tables 6 and 7 following give the records of the performance of the crude sets and the rerunning plant of the refinery for the year 1916, and the results of Engler distillations following, made by the refinery chemist, define the character and quality of the products manufactured in each apparatus. Except as concerns fuel consumption, no attempt is made by the refining company to record and compare the performance of the topping plant as opposed to that of the crude stills previously mentioned.

TABLE 6.—*Quantity of crude oil refined and of fuel consumed in crude stills and pipe retorts, Avon refinery, 1916.*

Month.	Volume of crude run.		Gravity.		Proportion of M. and B. S.	Volume of "tops" made.	Gravity.		Volume of fuel consumed.		Volume of residuum made.	Refining loss.
	Crude stills.	Pipe retorts.	°B.	Specific gravity.			°B.	Specific gravity.	Crude stills.	Pipe retorts.		
	Barrels.	*Barrels.*			*Per cent.*	*Barrels.*			*Barrels.*	*Barrels.*	*Barrels.*	*Barrels.*
January	.....	.....	25.4	0.9032	.....	115,778	50	0.7778	.....	.....	424,765	.....
February	398,684	133,320	26.0	.8974	.....	128,383	50	.7778	4,200.0	1,872.5	400,808	2,813
March	417,975	201,474	24.5	.906	0.5	150,084	50	.7778	4,566.6	1,918.5	466,394	2,971
April	445,141	151,209	26.0	.8974	.5	141,432	50	.7778	4,503.5	1,969.0	452,138	2,780
May	403,805	201,481	35.5	.9003	.5	148,016	50	.7778	4,509.0	2,452.2	453,981	3,289
June	389,221	194,985	25.0	.9032	.5	136,980	50	.7778	4,533.6	2,760.6	444,085	3,141
July	374,457	186,846	26.0	.8974	.5	133,395	50	.7778	4,405.5	3,475.5	424,547	3,361
August	391,025	189,743	26.0	.8974	.5	143,023	50	.7778	4,325.1	3,705.7	434,350	3,395
September	371,216	185,398	23.6	.912	.5	139,785	50	.7778	4,424.7	3,565.5	413,556	3,273
October	406,621	203,163	26.5	.895	.5	156,243	50	.7778	4,763.4	3,600.7	449,342	4,199
November	400,259	201,042	26.5	.895	.5	153,010	50	.7778	4,572.4	3,626.2	445,002	3,289
December	422,017	208,020	25.5	.9003	.5	157,162	50	.7778	4,779.0	3,911.4	469,713	3,662
Total	4,420,385	2,056,681	.....	.....	.....	1,703,291	.....	.7778	49,582.8	32,857.8	5,278,681	36,173
Average per month	401,853.1	186,971	25.5	.9003	.5	141,940.9	50	.....	4,507.5	2,987.1	439,890	3,288.4



ARRANGEMENT OF CONDENSER PIPING. BELL TOPPING PLANT, AVON REFINERY. FOR LIST OF MATERIALS SEE TABLE ON PAGE 20.

TABLE 7.—*Barrels of distillate run and products made in steam and combination stills, Avon refinery, 1916.*

Month.	Volume of tops run.	Volume of products made, barrels.				Refining loss, barrels.
		Gasoline.	Engine distillate.	Stove oil.	Steam still "bottoms."	
	Barrels.					
January	82,074	32,158	12,948	6,797	30,057	114
February	78,277	29,528	13,816	10,761	24,038	134
March	83,102	33,034	18,463	7,730	23,875	.....
April	79,951	31,625	17,522	4,714	25,967	123
May	83,974	34,118	23,723	927	28,064	142
June	114,319	40,307	34,769	6,773	32,281	189
July	156,864	56,034	45,716	22,296	32,561	257
August	152,306	57,715	44,339	19,076	31,176	.....
September	159,209	59,144	41,859	26,895	30,980	331
October	164,109	60,603	44,177	23,430	35,521	378
November	154,469	53,702	46,602	28,288	25,467	410
December	161,231	56,552	47,409	26,077	30,754	439
Total	1,469,885	541,520	391,343	183,764	350,741	2,517
Average per month	122,490.4	45,126.6	32,611.9	15,313.6	29,228.4	209.7

Results of Engler distillations of products.

[Distillations made by W. H. Peterson, refinery chemist.]

Gasoline, gravity 60.3° B. (specific gravity, 0.738), water content, 0.0.

Boiling point. °F.	Boiling point. °C.	Per cent over.
124 to 167	51.1 to 75	9.5
167 to 212	75 to 100	44.5
212 to 250	100 to 121.1	29.0
250 to 300	121.1 to 148.8	12.5
300 to 341	148.8 to 171.6	2.0
Bottoms (faint yellow).		1.1
Total		98.6

Engine distillate, gravity 51.4° B. (specific gravity, 0.773), water content, 0.0.

Boiling point. °F.	Boiling point. °C.	Per cent over.
216 to 250	102.2 to 121.1	32.5
250 to 300	121.1 to 148.8	49.0
300 to 350	148.8 to 176.6	14.5
350 to 390	176.6 to 198.8	2.5
Bottoms (trace yellow).		.8
Total		99.3

First-run distillate from toppers, gravity 49.6° B. (specific gravity, 0.781).

Boiling point. °F.	Boiling point. °C.	Per cent over.
160 to 212	71.1 to 100	8.5
212 to 250	100 to 121.1	21.5
250 to 300	121.1 to 148.8	28.0
300 to 350	148.8 to 176.6	17.0
350 to 400	176.6 to 204.5	11.5
Bottoms		13.0
Total		99.5

Steam-still "bottoms" gravity 39.3° B. (specific gravity, 0.828), open-cup fire, 128° F. (53.3° C.).

Boiling point. °F.	Boiling point. °C.	Per cent over.
302 to 347	150 to 175	28.0
347 to 392	157 to 200	30.0
392 to 437	200 to 225	21.0
437 to 482	225 to 250	13.0
Bottoms		8.0
Total		100.0

A meter on the fuel-oil line to the rerun stills showed them to be consuming oil fuel at an average rate of 0.92 per cent of the distillate treated.

STEAM CONSUMPTION.

The steam used consists of exhaust steam from the various pumps of the plant with the addition of enough live steam from the boilers to supply the requisite amount of heat.

Water is supplied to the boilers from a hot well of an average temperature of 165° F. through a Dow duplex pump, 10 by 8 by 10 inches. A series of readings gave the average stroke of this pump as 26.1 revolutions a minute with a corresponding average boiler pressure of 138 pounds. Allowing 10 per cent slippage for this pump, this is equivalent to 1,404.26 boiler horsepower developed. Of this amount the company charges about 350 boiler horsepower to the steam and combination stills—an estimated percentage that is approximately correct. Owing to the arrangement of the equipment it is not possible to determine actually the amount of steam used. The writer is indebted to Mr. C. Stamm, refinery superintendent, for the figures concerning steam consumption.

If the heat of the exhaust steam be considered as otherwise wasted energy, for each 100 barrels of crude oil treated in the topping plant the net heat expended to produce the various fractionated products from the oil treated is as follows:

	B. t. u.
Heating value in 1 barrel of this crude	6,063,800
Fuel used to treat 100 barrels of crude in topper, 1.6 barrels of 18° B. gravity	9,938,240
Fuel used in rerun plant to treat the distillate made from 100 barrels crude (0.92+24.2 barrels)	1,366,508
Heat used to make the steam supplied in treating 24.2 barrels of distillate (boiler efficiency 86 per cent)	1,930,870
Total net B. t. u. used in treating 100 barrels of crude	13,235,618
Total net B. t. u. used for 1 barrel of crude treated	132,356.2
	Per cent.
Proportion of fuel used to amount of crude run	2.18

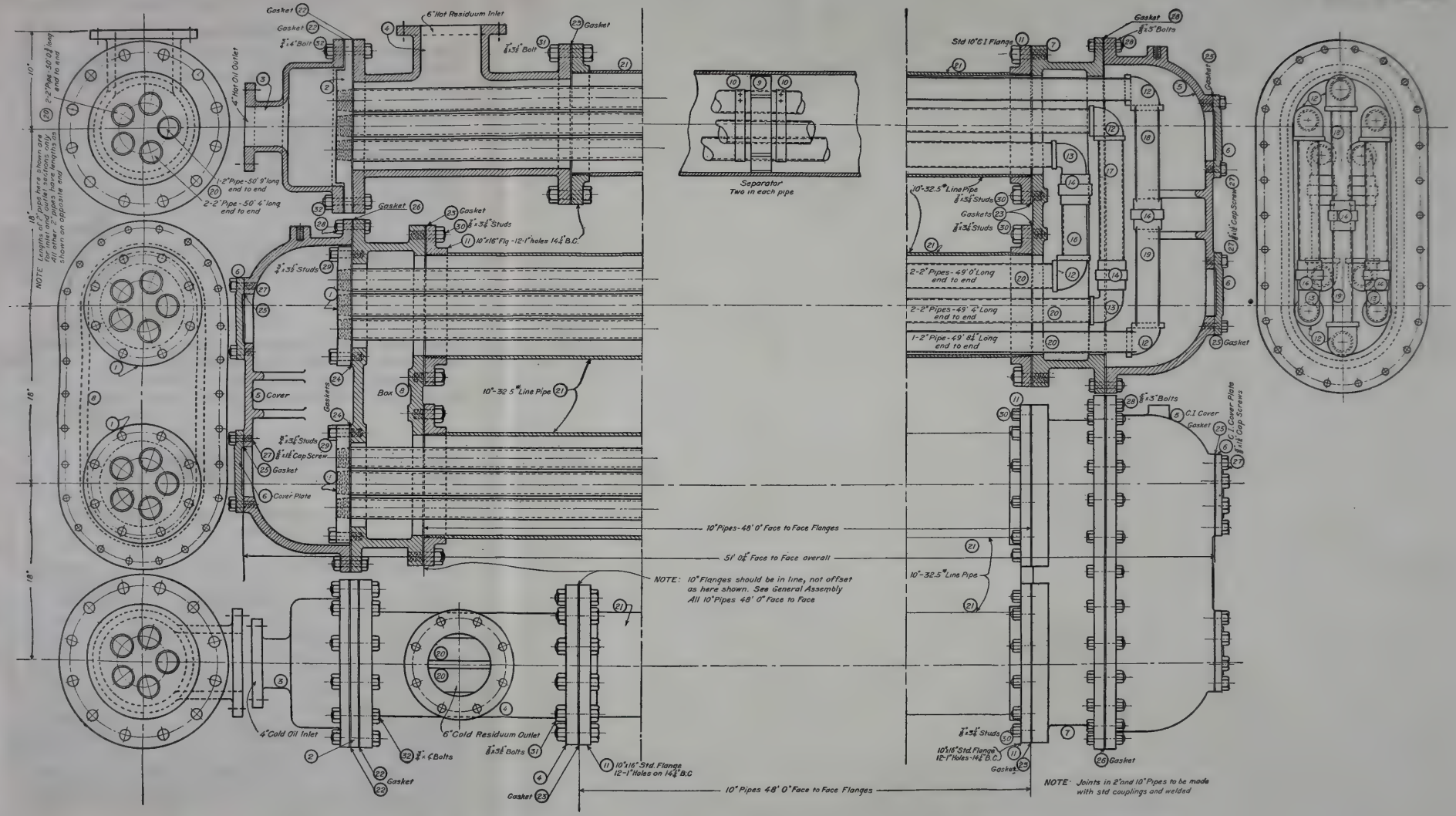
WATER CONSUMPTION.

The cooling water used in the condensers is not metered, and, except for the power required to deliver it, does not constitute a charge against the plant.

The revolutions of the pump show a delivery of 1,800 gallons a minute, an average of approximately 3.5 barrels of cooling water being used to one barrel of crude oil treated when the plant is operated at normal temperatures.

FLEXIBILITY.

Although this plant is running a clean oil of 26° B. gravity (specific gravity, 0.899), its adaptability is not confined to one oil. The Gaviota plant of this type, previously mentioned, is handling an oil of 18° to 20° B. (specific gravity 0.946 to 0.934) containing as high as 20 per cent briny water with equal efficiency, although the capacity, of course, is reduced. Oils that would cause foaming and frequent cleaning in the crude stills can be handled in the pipe retorts without trouble.



SECTION A-A ON GENERAL ASSEMBLY

SECTION B-B ON GENERAL ASSEMBLY

CONSTRUCTION DETAIL FOR HEAT EXCHANGER, BELL TOPPING PLANT, AVON REFINERY. FOR LIST OF MATERIALS SEE PAGE 24.

FIRE HAZARD.

No fires have occured with these toppers during operation, and the No. 1 plant has been operating continuously since August 1, 1915.

REPAIRS.

Topper No. 2 began operation in January, 1916, and the only repair necessary was in connection with the burning of two tubes in May; new tubes were quickly fitted to replace those destroyed. The repair charges have therefore been minimum. The light auxiliary walls inclosing the fittings at the ends of the tubes probably justify themselves, as they result in a distinct heat saving, and, being constructed of weak mortar, are easily removed when repairs are necessary. It should be noted that little time is wasted in waiting for the retorts to cool for repair work, as the work is performed entirely from the exterior of the furnace.

COST DATA.

COST OF LABOR.

The pay roll given on page 10 constitutes the daily labor charge for operation against the entire refinery. Practically this charge should be divided between the crude stills and the toppers, proportionately to the crude run, and the toppers should therefore be charged $24. 47 a day.

COST OF TOPPING PLANT.

An approximate estimate of the cost of construction of the topping plant, based on costs of labor and material in 1914, is given in Table 8 following.

TABLE 8.—*Cost of constructing Bell topping plant, Avon refinery.*

Item.	Excavation.	Concrete.	Brickwork.	Ironwork.	Unit.	Pumps.	Pipe covering.	Piping.	Total.
TOPPERS.									
2 toppers and stack complete.	.....	$694	$4,642	$1,780	.....	$632	$406	$4,400	$12,554
2 towers	$20	100	.....	.....	$2,446	.....	.....	.....	2,566
2 heat exchangers	.....	500	.....	904	.....	.....	.....	6,120	7,524
4 condensers	316	2,552	.....	1,112	4,600	.....	.....	6,952	15,532
2 look boxes	.....	.....	.....	.....	1,200	.....	.....	.....	1,200
Interconnecting piping, fittings and labor	.....	.....	.....	.....	.....	.....	.....	5,000	5,000
Total	336	3,846	4,642	3,796	8,246	632	406	22,472	44,376
STEAM AND COMBINATION STILLS.									
4 combination stills and towers	$1,628	$4,588	$12,124	$8,880	$15,760	$3,276	$1,120	$5,784	$53,160
2 steam stills and towers	226	1,589	843	3,200	5,400	.....	308	4,508	16,074
10 condensers	790	6,380	2,780	.....	11,498	.....	.....	17,379	38,827
6 look boxes	.....	.....	.....	.....	.....	.....	.....	3,600	3,600
Total	2,644	12,557	15,747	12,080	32,658	3,276	1,428	31,271	[a]111,661

[a] Of this total, $75,930 is chargeable to crude-still battery, and $35,731 is chargeable to the Bell toppers.

COST PER BARREL OF CAPACITY.

Considering the proportionate charge of the rerunning plant for the amount of distillate handled from the toppers, the entire first cost of a plant of this type is estimated at $80,087, or $12.80 per barrel of normal daily capacity.

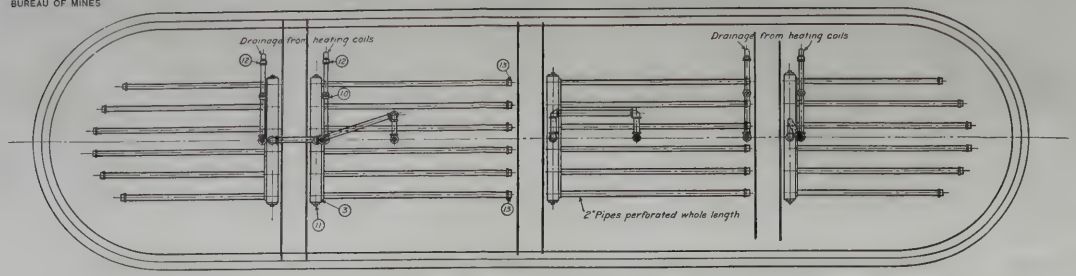
CHANGES AND IMPROVEMENTS POSSIBLE.

Probably many improvements can and will be made in the construction of the various units as the necessity of saving heat becomes more insistent.

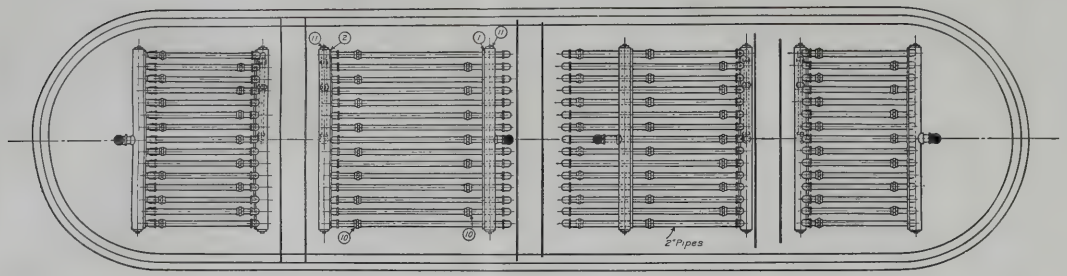
The furnace construction might be changed to enlarge the combustion chamber, as the experiments subsequently discussed indicated that the damper and the air supply could not be adjusted to reduce the proportion of excess air below 50 per cent of that required. In the writer's opinion it is questionable whether even that rate of combustion could be maintained without superheating the coils. With a larger combustion chamber removing the flames from direct contact with the pipes the proportion of excess air could undoubtedly be reduced; also the coils might be raised somewhat higher to advantage. As with other furnaces of various types, it is the writer's opinion that the air required for combustion could be preheated by passing it through a flue under the combustion chamber, resulting in a saving of fuel and also in a beneficial effect on the foundations by reducing the excessive temperature stresses in them. This flue could be equipped with a damper for regulating the air supply. The tendency around a refinery is to regard oil fuel a plentiful and therefore a cheap commodity; moreover, it is a fuel easily fired and easily wasted.

The separating towers used with the topper cause the oil and the vapors to be intimately associated during the separation; that is, vapors do not instantly leave the oil upon separation, and absorption of the vapors, combined with the mechanical entraining of discoloring heavy oils, undoubtedly occurs. Residuum from the toppers running at the same temperature as that of the crude stills on the same oil flashes at about 10° F. lower temperature. Also the first-run distillate from the toppers is somewhat discolored. Any distillates absorbed by the residuum results in clear loss unless the residue is to be further fractionated.

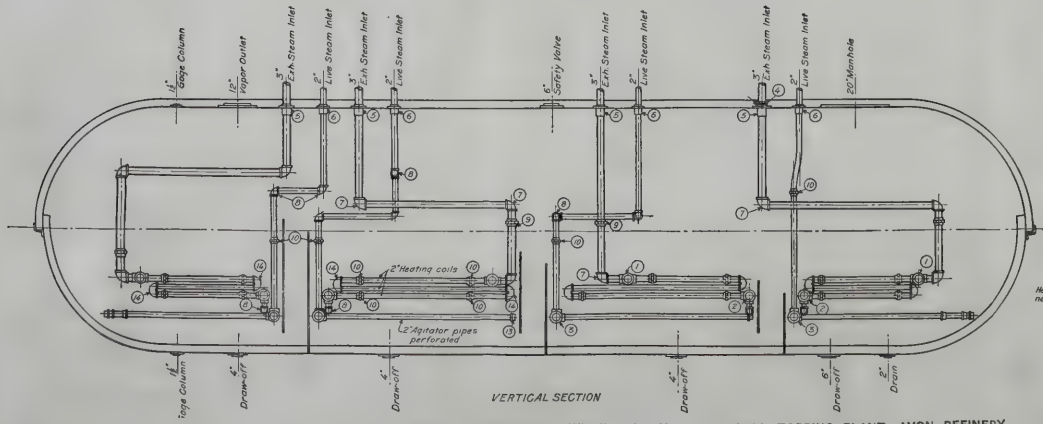
In the rerunning plant the tower used undoubtably accomplishes the desired result—the production of water-white homogenous fractions. Also owing to the absorption obtained by the incoming distillates, unquestionably a large percentage of the light gases is recovered, and the refining losses are materially reduced. The Avon company is now operating its steam and combination stills in series, charging each successive still through its tower with the residue from



PLAN VIEW OF PIPES FOR STEAM AGITATION



PLAN VIEW OF PIPES FOR STEAM HEATING



PIPING ARRANGEMENT WITHIN STEAM STILLS, BELL TOPPING PLANT, AVON REFINERY.

the preceding still. With this method each still operates at a fixed temperature higher than that of the preceding one. The results obtained have been highly satisfactory, more capacity being obtained and the quality of the product being improved.

The heat exchangers are an excellent type and show a high rate of transfer. With the smaller size of jacket used in the cylindrical still set, the rate is greatly increased over that with the 10-inch jacket used with the toppers. The results clearly show that the heat transfer rate is greatly increased with increased velocities of the fluid.

Finally, fractional cooling of the first-run distillate would materially reduce the steam-still capacity required. The steam-still "bottoms" at least could be removed from the first-run distillate by fractional cooling, and as they constitute about 25 per cent of the first-run distillate the saving would be material.

DATA REGARDING EXPERIMENTS.

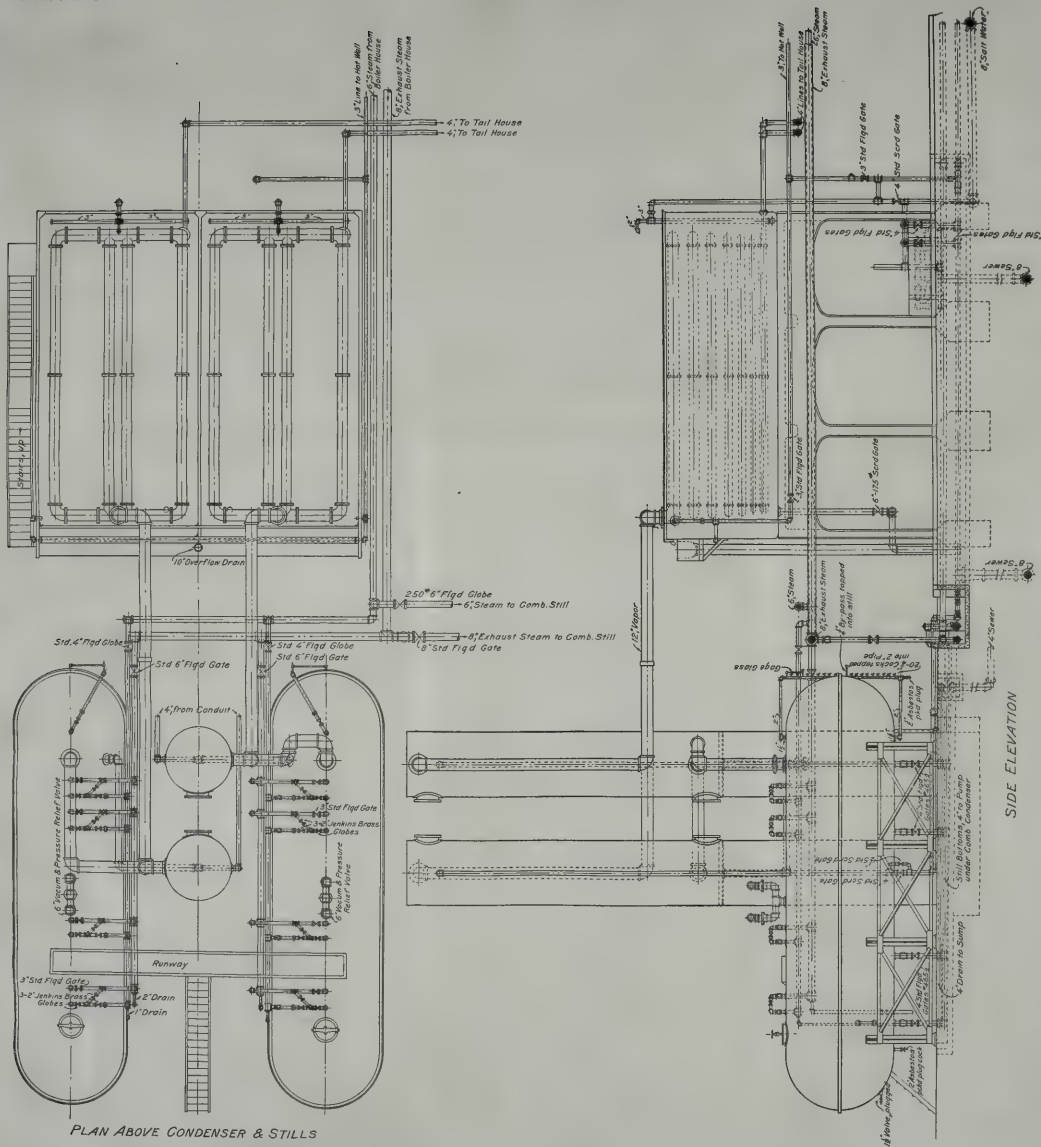
Various experiments were made with the different apparatus during the writer's inspection of the plant, with a view to determining the efficiency of each. The results are given in the test and tables following.

TABLE 9.—*Results of analyses of flue gas in Bell topping plant, Avon refinery.*

Apparatus.	Number of test.	Percentage by weight.				Percentage by volume.				Air required per pound of fuel.	Air used per pound of fuel.	Excess air.	Weight of flue gas per pound of fuel.
		CO_2.	O.	CO.	N.	CO_2.	O.	CO.	N.				
										Pounds.	*Pounds.*	*Per cent.*	*Pounds.*
Combination stills	1	7.6	17.4	.....	74.8	5.1	16.0	.....	78.9	13.96	40.0	186.0	41.09
Do	2	5.7	17.8	.....	76.2	3.8	16.3	.....	79.9	.....	54.5	290.0	54.78
Boilers (4 150-horsepower, 2 175-horsepower)	3	11.1	10.8	.....	78.0	7.4	10.0	.....	82.6	.....	29.3	110.0	26.68
Boilers (2 200-horsepower)	4	10.4	13.0	0.19	75.2	7.0	13.0	0.2	79.8	.....	28.6	104.0	29.44
Toppers	5	10.3	13.4	.....	76.4	7.0	12.5	.....	80.5	.....	29.7	113.0	30.13
Do	6	12.0	10.8	.....	78.0	8.1	9.4	.....	82.5	.....	26.4	88.0	26.54
Do	7	11.8	10.7	.....	77.1	8.0	9.9	.....	82.1	.....	26.6	90.0	25.54
Do	8	14.7	7.9	.....	78.0	10.0	7.4	.....	82.6	13.96	21.4	53.0	21.4
Do	9	14.7	5.5	.38	79.5	9.9	5.1	.4	84.6	.....	21.3	52.0	20.54

TABLE 10.—*Data regarding furnace and stack temperatures in Bell topping plant, Avon refinery.*

Apparatus.	Number of test.	Atmospheric temperature.		Stack draft, inches water.	Observed furnace temperature.		Stack temperature.		Weight of the gases per pound of fuel.	Computed temperature of combustion.		Heat loss from excess air.		Fuel loss.	Furnace efficiency.	Remarks.
		°F.	°C.		°F.	°C.	°F.	°C.		°F.	°C.	B. t. u.	Calories.			
									Pounds.					*Per cent.*	*Per cent.*	
Combination stills	1	58	14.4	0.35	.....	.....	506	263.3	41.09	1,809	987.0	2,796	704.6	16.6	35.0	Normal operation.
Do	2	58	14.4	.....	.....	.....	.....	.....	54.78	1,359	737.0	4,500	1,170.0	24.6	26.0	Do.
Boilers (2 175-horsepower, 4 150-horsepower)	.....	.....	.....	.26	1,765	962.6	560	293.3	.....	.....	.....	.....	.....	.....	.....	Do.
Boilers (2 200-horsepower)	3	58	14.4	.26	1,650	899.0	450	232.2	28.68	2,590	1,421.0	1,890	477.0	7.7	47.5	Do.
Toppers	5	58	14.4	.23	No.1, 1,680 No.2, 1,640	915.5 893.3	385	196.1	30.13	2,473	1,356.0	1,321	333.0	7.1	47.0	Do.
Do	9	58	14.4	.....	.....	.....	385	196.1	20.54	3,632	2,000.0	557.6	136.0	2.9	66.0	Air supply one-half closed. Dampers seven-eighths closed.



GENERAL ARRANGEMENT OF STEAM STILLS AND PIPING, BELL TOPPING PLANT, AVON REFINERY.

TABLE 9. *Results of analyses of flue gas in Bell topping plant, Avon refinery.*

In the computations represented in the foregoing tables use was made of the following data:

Ultimate analyses of fuel oil.

	Per cent.
Carbon	85.6
Hydrogen	11.89
Oxygen	0.9
Nitrogen	0.52
Sulphur	1.09
Calorific value	18,640 B. t. u. (4,697.28 calories)

FORMULAS USED IN COMPUTATIONS.

1. Air required per pound of fuel for perfect combustion:

$$A=34.56\left(\frac{C}{3}+H-\frac{O}{8}\right)+\frac{S}{8}=13.96 \text{ pounds.}$$

where A=weight of air required per pound of fuel.
S, C, H, and O are proportional parts by weight of elements in the fuel.
34.56=number of pounds of air theoretically required for combustion of 1 pound of H.

2. Air actually supplied per pound of fuel:

$$A=3.032\left(\frac{N}{CO_2+CO}\right)\times C.^a$$

where A=weight of air supplied by pound of fuel.
N, CO, and CO_2=percentages of elements by volume in flue gases.
C=the proportion by weight of carbon in the fuel.

3. The weight of flue gases, W, per pound of fuel burned=

$$\frac{11\,(CO_2)+8\,(O)+7\,(CO+N)}{3(CO_2+CO)}\times 85.6\,(C)^b$$

where CO_2, O, CO, and N are percentages by volume, taken from the flue gas analysis.

4. The heat lost in the flue gases per pound of fuel burned:

$L=0.24\,W\,(T-t)$
where L=B. t. u. lost per pound of fuel burned.
W=weight of flue gases in pounds per pound of dry fuel.
T=temperature of flue gases.
t=temperature of atmosphere.

5. Furnace efficiency:

$$E=\frac{\text{Air required for perfect combustion}}{\text{Air used for combustion}}$$

6. Temperature due to combustion:

$$t=\frac{h}{ws}$$

where h=heat liberated (B. t. u. per pound fuel).
w=weight of gaseous products.
s=specific heat of gaseous products.
t=temperature due to combustion.

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[a] Formula from Report of the committee on the revision of the Society code of 1885, relative to a standard method of conducting steam boiler trials: Trans. Am. Inst. Mech. Eng., vol. 21, 1900, p. 94; see also Marks, Lionel, Mechanical engineer's handbook, 1916, p. 891.

[b] Formula from Marks, Lionel, Mechanical engineer's handbook, 1916, p. 891.

Laboratory distillations of the crude run in the topper showed that the oil contained the following fractions in the proportions given:

Results of laboratory distillations of crude run in topper, Avon refinery.

[Gravity of oil sample, 25.6°B. (specific gravity, 0.900).]

Boiling point.		Specific gravity of fraction.	Per cent of crude evaporating.		Specific gravity of fraction.	Residue remaining.	
°F.	°C.		By volume.	By weight.		By volume.	By weight.
160 to 212	72.2 to 100	0.700	2.5	1.94	0.903	94.5	94.73
212 to 250	100.0 to 121.1	.720	5.25	4.2	.913	89.25	90.53
250 to 300	121.1 to 148.8	.742	7.00	5.77	.928	82.25	84.76
300 to 350	148.8 to 176.65	.767	4.00	3.41	.930	78.25	81.35
350 to 400	176.65 to 204.4	.790	2.75	2.41	.932	75.50	78.94
400 to 450	204.4 to 232.2	.806	3.38	3.10	.938	72.12	75.84
Water		1.0	3.0	3.33			

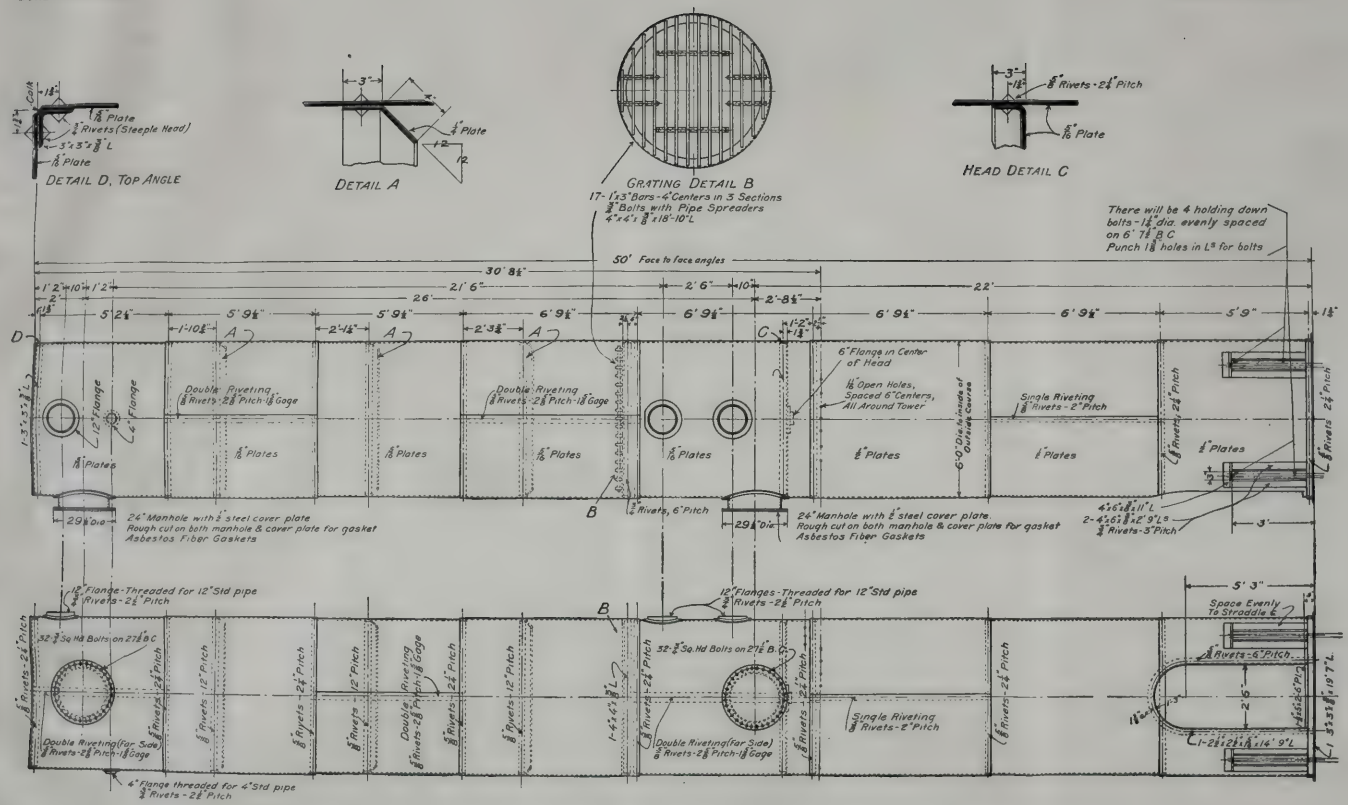
Assuming no loss of heat occurs in the apparatus and considering the heat recovered in the exchangers, the theoretical fuel consumption to remove the above cuts from one pound of this crude oil would be as follows:

Where the mean specific heat of the oil = 0.45, approximately,
latent heat of distillate =125 British thermal units
specific heat of vapors = 0.5, approximately,
oil leaves the heat exchangers at 250°F., approximately.

		B. t. u.
Heat 0.905 pounds of oil 250–300° F	0.905 (250–300) ×0.45=	20.30
Evaporate 0.057 pounds of distillate	.057×125 =	7.12
Superheat 0.119 pounds of vapors 250–300	.119 (250–300) × .5 =	2.99
Heat 0.847 pounds of oil 300 to 350°F	.847 (300–350) × .45=	19.01
Evaporate 0.034 pounds of distillate	.034×125 =	4.25
Superheat 0.153 pounds vapors 300–350	.153 (300–350) × .5 =	3.83
Heat 0.613 pounds of oil 350–400	.813 (350–400) × .45=	18.30
Evaporate 0.024 pounds of distillate	.024×125 =	3.00
Superheat 0.177 pounds vapors 350–400	.177 (350–400) × .5 =	4.43
Heat 0.789 pounds of oil 400–450	.789 (400–450) × .45=	17.73
Evaporate 0.031 pounds distillate	.031×125 =	3.88
Superheat 0.208 pounds vapors 400–500	.208 (400–450) × .5 =	5.20
Heat consumed per pound of oil topped at 100 per cent efficiency		=110.04

If dry oil is being run through the toppers, it is the practice to add 3 per cent of water to the oil, as experience has shown that the added steam causes the coils to give less trouble. Considering the heat used then in making steam of this water:

		B. t. u.
Evaporate 0.033 pounds of water	0.033×970=	29.11
Superheat 0.033 pounds of steam (212–450°F.)	×0.5=	3.57
		32.68
		110.04
Total heat consumed to top 1 pound of this oil at 100 per cent efficiency		=142.72



SEPARATING TOWER FOR STEAM AND COMBINATION STILLS, BELL TOPPING PLANT, AVON REFINERY.

One barrel of 26° B. oil weighs 314.4 pounds; therefore the total heat required to top one barrel of this oil at 100 per cent efficiency would be:

$$142.72 \times 314.4 = 44,771.17 \text{ B. t. u.}$$

The record of fuel consumed in 1916 shows 0.0159 barrel of fue used to 1 barrel of oil topped, or, with 18° B. gravity fuel, 98,761.26 British thermal units. The over-all efficiency of the battery of toppers is therefore:

$$\frac{44,771.17}{98,761.26} = 45.2 \text{ per cent.}$$

HEAT EXCHANGERS.

The averages of a series of daily readings of temperatures of the fluids passing the heat exchangers during the month of November, 1916, are tabulated below, with the computed rates of heat transmission obtained in the apparatus.

Average temperatures of residuum and crude oil in heat exchangers, Avon refinery, November, 1916.

Average number of barrels of residuum each hour.	Gravity per barrel.		Weight per barrel.	Temperature of residuum.				Heating surface.
				Ingoing.		Outgoing.		
	° B.	Specific gravity.		° F.	° C.	° F.	° C.	Square feet.
99.4	18	0.9465	*Pounds.* 331.2	390.4	199.0	152.4	66.5	28,89.21

Average number of barrels of crude each hour.	Gravity per barrel.		Weight per barrel.	Temperature of crude.				Heat transmitted per square foot, per hour, per degree of mean temperature difference (K).	Heat seemingly transmitted per square foot, per hour, per degree of mean temperature difference (K_1).
				Ingoing.		Outgoing.			
	° B.	Specific gravity.		° F.	° C.	° F.	° C.		
135.15	26	0.8984	*Pounds.* 314.4	86.1	30.0	245.6	118.5	*B. t. u.* 1.04	*B. t. u.* 10.7

Where $K = \frac{F\,S\,(t-t_1)}{H\theta_m}$ = the British thermal units of heat received from residuum by crude oil per square foot per hour per degree mean temperature difference.

$K_1 = \frac{F_1\,S\,(t-t_1)}{H\theta_m}$ = the British thermal units of heat seemingly transferred to crude oil per square foot per hour per degree of mean temperature difference.

K should equal K_1 but for the heat lost in radiation by the residuum from the 10-inch jacket to the atmosphere.

F = weight of fluid passing per hour.

S = specific heat of fluid, 0.4 for residuum, 0.45 for crude.

H = heating surface of the exchanger.

$$\theta_m = \frac{\theta a - \theta \epsilon}{\log_e \frac{\theta_a}{\theta \epsilon}} = \text{mean temperature difference.}$$

BREA PLANT.

GENERAL DESCRIPTION.

One of the first and largest topping plants of nondistinctive design in California is that at Brea, Orange County. It was erected in 1911 and has been running continuously since then to dehydrate and top the oils produced in the Fullerton field. The tops and residue supply the local market with motor spirits and fuel oil.

In general, the plant consists of two batteries of pipe retorts and two batteries of four 40-horsepower boiler stills each, all served by seven condensers of the open submerged type. Each of the pipe retorts is provided with a vapor separating tower and a small heat exchanger. The residuum from these exchangers is run through a cooler, consisting of a 3-inch coil in a shallow water tank.

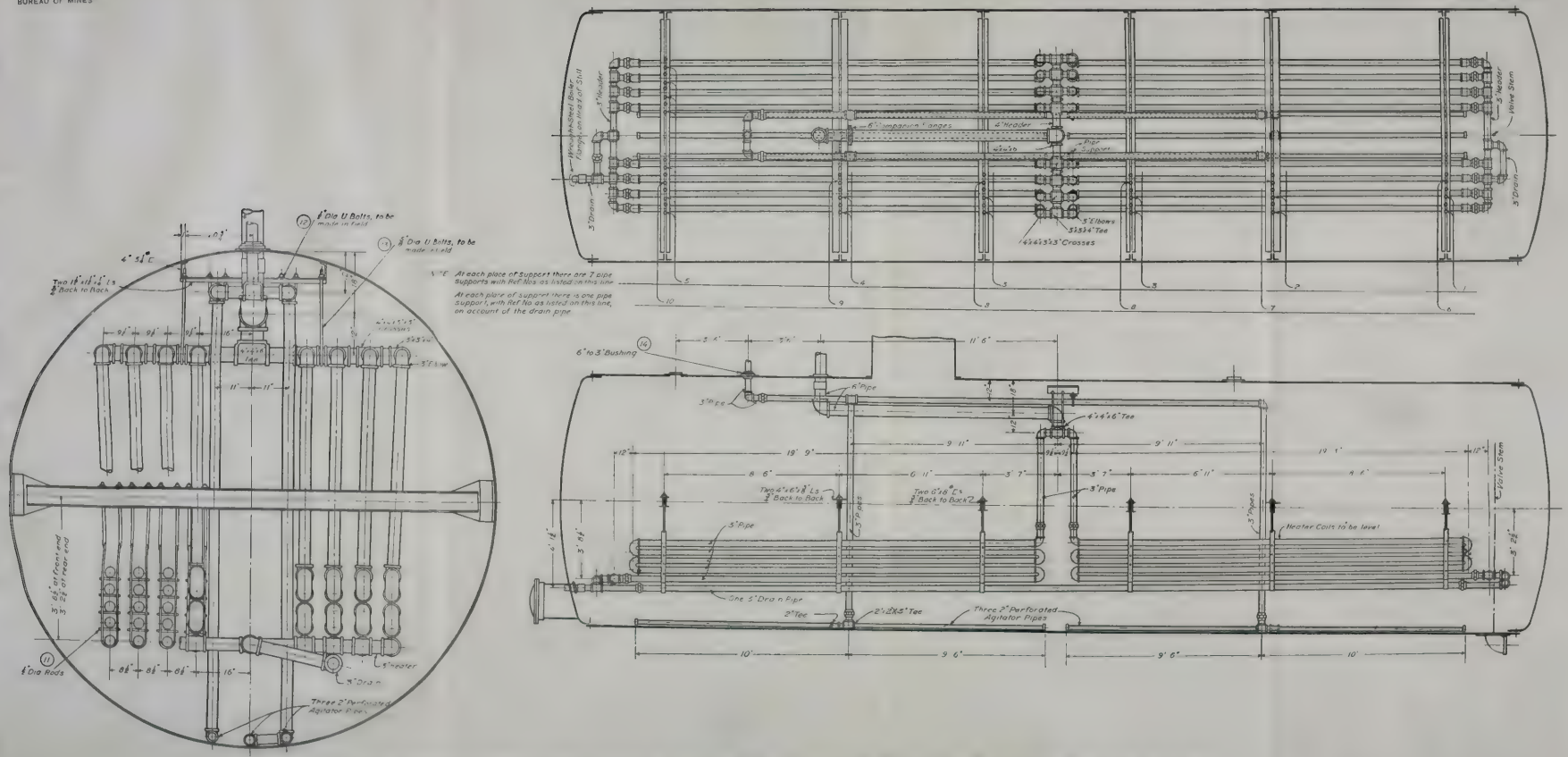
The two batteries of boiler stills feed one small vapor separator and are served by a total of four heat exchangers and one residuum cooler.

A small rerunning plant consisting of three steam stills, one heat exchanger, and three dephlegmators and condensers, is used for fractionating some of the first-run distillate. Three condensers identical with those of the crude sets serve to further cool these fractions before they reach the tail house. Steam for the entire plant is supplied by a battery of five 80-horsepower tubular boilers.

DETAILED DESCRIPTION OF APPARATUS.

PIPE RETORT BATTERIES.

Both batteries of retorts are placed in a single brick setting whose over-all dimensions are approximately 20 by 20 feet by 14 feet in height. Red-brick walls, faced within by fire brick, built to these outside measurements inclose the batteries, and a middle division wall divides the setting into two compartments. Within the upper part of each compartment six horizontal rows each of eight 3-inch pipes 20 feet long are supported by the brickwork and are connected end to end to form a continuous coil. An auxiliary coil of short 3-inch pipes, placed at right angles to the other pipes and similarly supported, is arranged to supply two intermediate rests for each row of



PIPING ARRANGEMENT WITHIN COMBINATION STILLS, BELL TOPPING PLANT, AVON REFINERY. FOR LIST OF MATERIALS, SEE TABLE ON PAGE 26.

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the main coil. These coils are connected in series with each other, forming a continuous path for oil through the batteries. The pipe connections for the main coil extend just beyond the outside of the brick walls, and sheet-iron covers are provided to reduce the radiation losses. The prewarming-coil connections are not protected. Oil enters the prewarming coil of each battery at the bottom and is forced upward and into the top row of the main coil. Thence it travels back and forth and downward successively through each row to the exit from the inside pipe of the bottom row.

The bottom row of pipes is about 5 feet above the floor of the setting, and this lower part of the compartment forms the combustion chamber in each battery. Combustion gases make one pass over the coils, leaving through short stacks mounted on top of the setting opposite to the end where the burners are placed. The fuel oil used is atomized by steam through these burners, the feed being

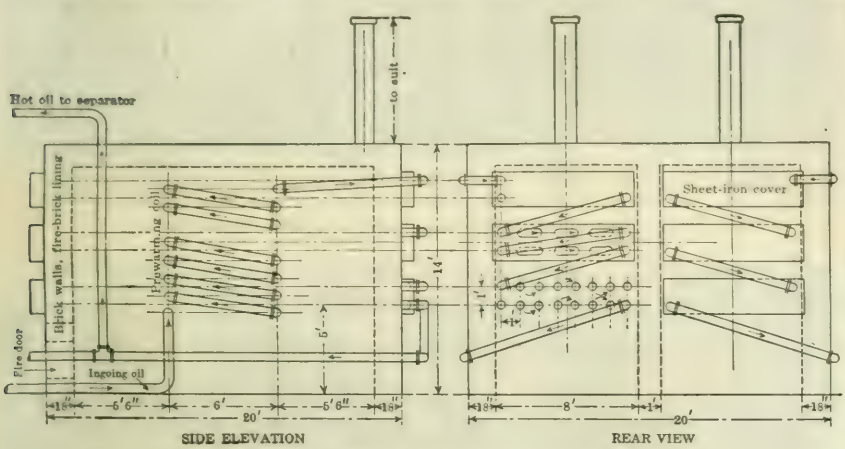


FIGURE 2.—Pipe retorts, Brea topping plant.

regulated by valves on the front of each furnace (see fig. 2). Plate XVII shows this battery with its accompanying separating towers.

BOILER STILL BATTERIES.

Each battery consists of four 40-horsepower California type of tubular drilling boilers, set adjacent to each other at successive levels, to permit a gravity flow between them. They are placed in a common setting, each with a separate combustion chamber and stack. Combustion gases are given one pass under the stills and a second pass through the tubes to the stack.

Two 4-inch headers, one in front and one in the rear of each battery, are connected by one or more 4-inch pipes to each still. Valves are placed between each of these connections to permit the isolation of any still from the system during repairs. Oil enters the highest

still opposite to the end fired, flows through it and out to the next still, finally leaving from the last and lowest still as residuum which passes to the heat exchangers. Vapors evolved in the stills are collected by a 6-inch vapor header connected to the domes and terminating at a small vapor separator. Small perforated steam pipes are provided near the bottom of each still for agitating the

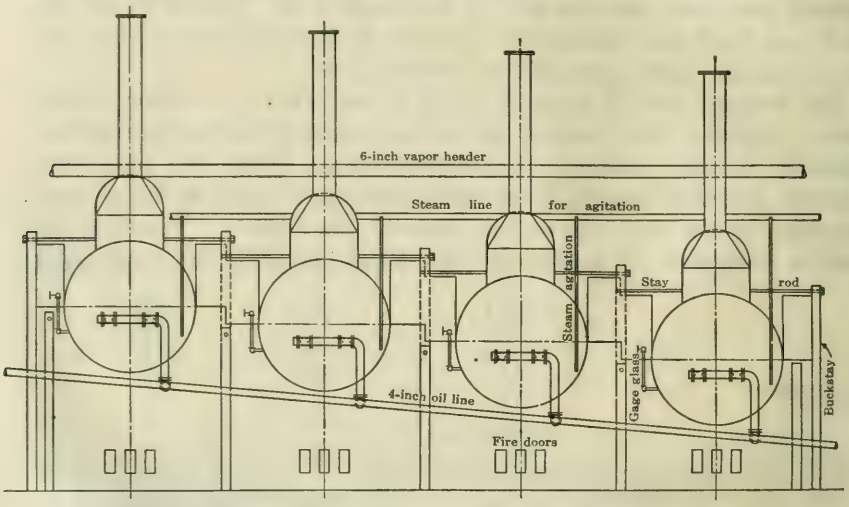


FIGURE 3.—Elevation of four 40-horsepower boiler stills, Brea topping plant.

oil and assisting the vaporization of the light tops. Plate XVIII and figures 3 and 4 illustrate this construction.

PIPE-RETORT SEPARATING TOWERS.

These pipe-retort separating towers (Pl. XIX, *A*), each consist of a vertical cylindrical steel shell, 25 feet high and about 5 feet in diameter, with flat top and bottom plates riveted to the sides. Hot oil from the retorts enters the tower about 15 feet from the bottom through a 4-inch jacketed line flanged to the side and extending into the middle of the chamber. By means of suitable fittings the oil entering is deflected downwards and finely divided in falling to the bottom. A 4-inch residuum draw-off is placed about 2 feet from the bottom and sealed to maintain a constant 5-foot level in the tower. Vapors separated from the finely sprayed oil rise to the top and are withdrawn through a 6-inch vapor take-off line extending to the condensers.

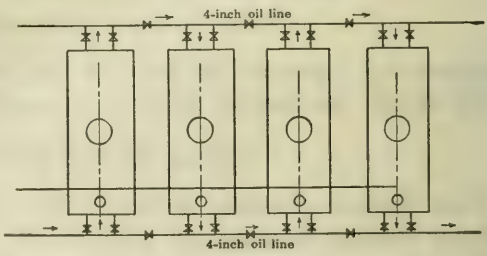
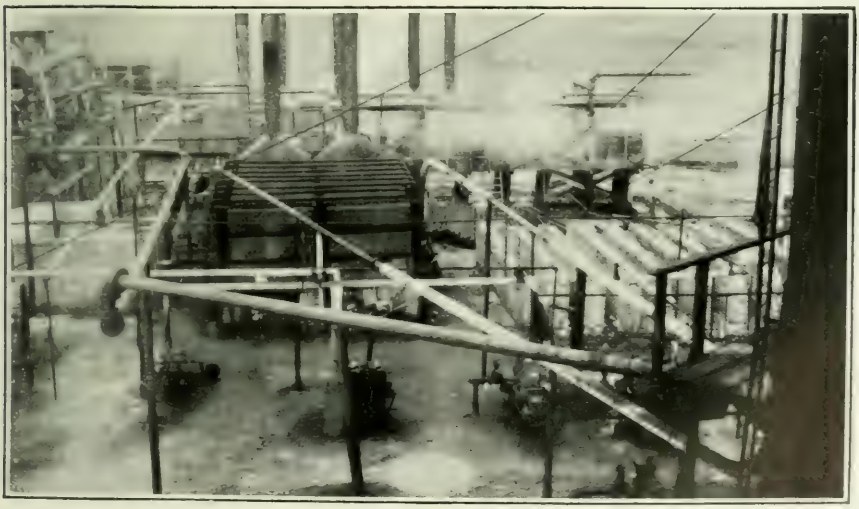
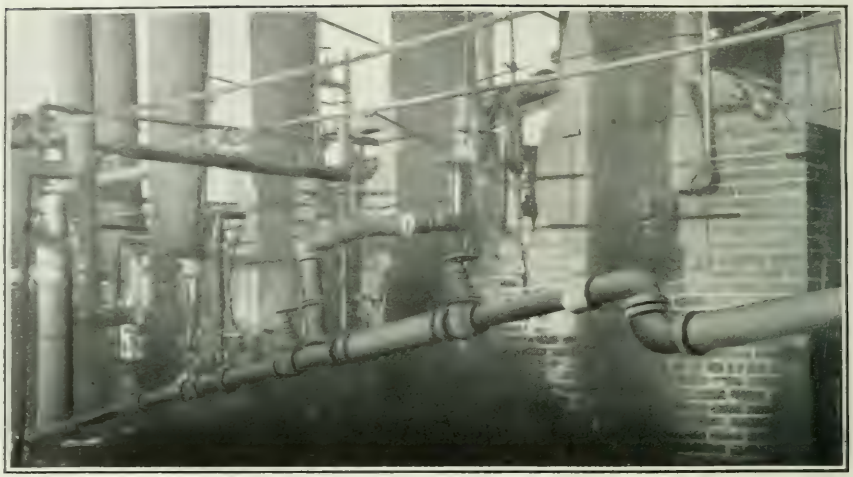


FIGURE 4.—Diagram showing arrangement of oil lines for stills in figure 3.

A. BREA PIPE RETORTS AND SEPARATING TOWERS. NOTE JACKETED HOT-OIL LINE.



B. BREA PIPE RETORTS, WITH CONDENSERS IN BACK GROUND.



A. BATTERY OF BOILER STILLS SHOWING INTERCONNECTING PIPING.

B. GENERAL VIEW OF BOILER STILLS. BREA REFINERY. NOTE SMALL SEPARATOR BELOW X.

VAPOR SEPARATOR FOR BOILER STILLS.

A small separating chamber is provided with these stills. It is a hollow cylinder about 8 feet high and 6 feet in diameter into which the 6-inch vapor lines from each battery are connected near the top. An 8-inch line similarly connected joins this separator to the condensers.

The function of this separator normally is to collect distillate emulsion, which would otherwise foul the condensers. Foaming induced from running a wet oil can always be detected and frequently can be checked before the chamber fills and overflows to the condensers. A gage glass on this chamber shows the oil level, which normally remains steady, but when foaming occurs the level fluctuates rapidly up and down through the glass. Foaming, unless caused by a small quantity of water in the oil momentarily passing the stills, can be checked only by extinguishing the fires. The hot oil is then circulated through the battery until it has cooled sufficiently to prevent coking which might otherwise occur. The boiler stills are used for a dry oil only, though occasionally a small quantity of water carried in suspension from the storage tanks enters them unavoidably. Plate XVIII, *B*, shows this separator connected in the vapor lines immediately beyond the nearer battery.

HEAT EXCHANGERS.

Each heat exchanger is composed of two 20-foot lengths of 16½-inch pipe flanged together and fitted with a special manifold head on either end. Between the manifolds, four 40-foot lengths of 3-inch pipe are connected, and a partition in each manifold forces the cold oil flowing through these pipes to travel back and forth through each length in series. The hot outgoing residuum surrounds the pipes and flows roughly countercurrent to the oil, making one pass through the apparatus. Two exchangers serve both pipe retorts and four are provided for the boiler stills.

THE CONDENSERS.

Ten condenser boxes of wooden construction are provided. They are 10 feet wide and 42 feet long, and each contains one or more coils of pipe submerged in the cooling water. No similarity in design exists with these coils as they are mainly constructed from apparatus discarded or unsuitable for other purposes. It will be noted that with five of the boxes one or more 14-inch vapor pipes, 40 feet long, are connected with the submerged coils and sprayed by the entering cooling water. Figure 5 shows the construction of each box and the number of pipes provided. The cooling water gravitates from the condensers to a wooden tower, about 40 feet by 40 feet by 20 feet high. The sides of the tower are constructed of small horizontal

louvers set close together at 45-degree angles and supported by a wooden framework. The water is sprayed through the atmosphere from the top within the tower and is cooled by partial evaporation. A Worthington duplex pump, 14 by 10¼ by 12 inches, returns the water from the shallow reservoir below the tower to the condensers.

RESIDUUM COOLERS.

Two residuum coolers complete the apparatus used with the crude set. Each is a shallow wooden box about 12 feet wide and

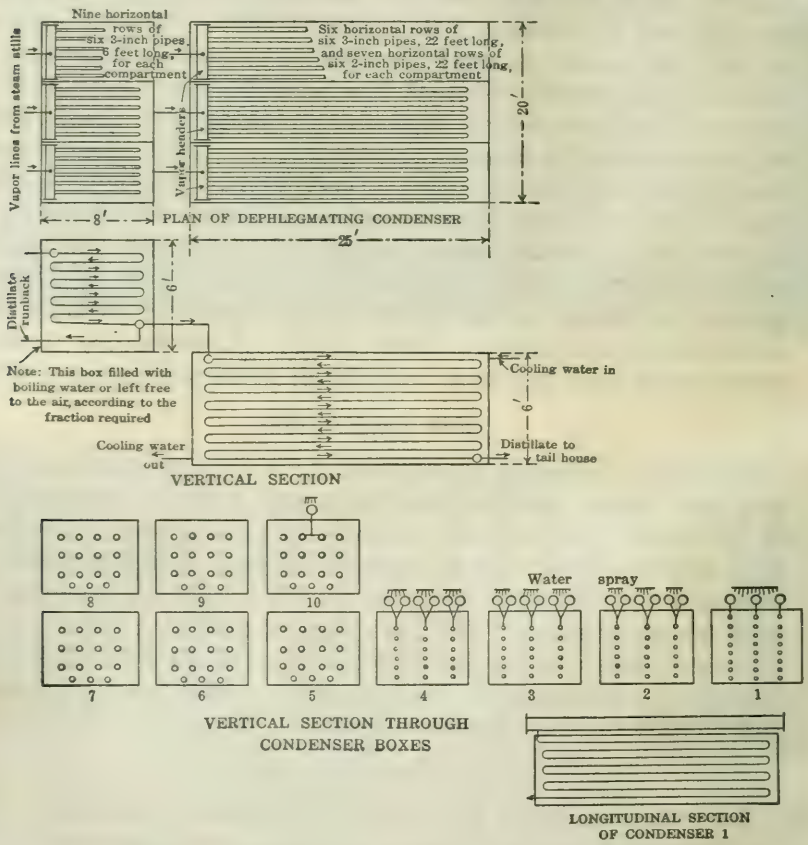


FIGURE 5.—Dephlegmator and condensers, Brea topping plant.

42 feet long containing a continuous coil of eight 3-inch pipes each 40 feet long connected by return bends and submerged in the cooling water. The water enters at one end of the box and by appropriate baffles is caused to flow countercurrent to the residuum.

STEAM STILLS.

The steam stills used in rerunning are identical with the stills described on page 72 and shown in Plate XXV. They are cylindrical stills 6 feet in diameter and 28 feet long with dished heads, upon one of which a special manifold with removable cover plate is riveted. Into this manifold three banks of twenty-seven 1¼-inch return tubes are fitted, through which steam flows in series, guided by baffles in the manifold. Oil to be treated surrounds the steam pipes, and in passing through the still flows opposite to the steam, guided by vertical baffles. The three stills are connected for continuous running, a Worthington pump, 5¼ by 4¾ by 5 inches, receiving the oil from one still for transfer to the next. Vapors evolved in the stills collect in a large dome mounted on each still and pass to the dephlegmating condensers. A 2-inch pipe connected to this dome returns heavy distillates to the stills from each dephlegmator.

HEAT EXCHANGER.

One heat exchanger, as previously described using exhaust steam, is used for prewarming the oil treated in these stills.

DEPHLEGMATORS AND CONDENSERS.

The dephlegmators comprise a steel box 8 feet wide by 20 feet long and 6 feet high, divided by two vertical partitions into three compartments. Each compartment contains six vertical coils, each of nine horizontal 3-inch pipes, 6 feet long, connected by return bends. At the top a header is connected to the ends of these coils in each compartment, and a similar header joins the other ends at the bottom. Vapors enter the coils through the top header and pass downward through them to the lower header. The compartments contain boiling water, or the coils are air-cooled according to the fractions required. The condensate from the lower header of each dephlegmator returns to its still.

A steel box 20 feet wide and 25 feet long by 6 feet high is placed just below the dephlegmators. It is divided longitudinally by two vertical partitions into three compartments, each containing six vertical coils of six 3-inch and seven 2-inch horizontal pipes fitted with top and bottom headers. Cooling water enters each compartment at the top and surrounds the coils, leaving at the bottom. Uncondensed vapors from the dephlegmators pass to these condensers and as condensate flow to the wooden box condensers previously described, where they are further cooled before going to storage (see fig. 5, p. 42).

METHOD OF OPERATION.

Crude oil enters the plant through two Worthington duplex pumps, 7½ by 4½ by 10 inches, at atmospheric temperature (about 80° F., 26.6° C.) and is forced through the heat exchangers for each battery in parallel, leaving for the stills or pipe retorts at about 150° F., (65.5° C.). Two large crude supply tanks are provided, and dry oil only is fed to the boiler stills by one pump. The pipe retorts handle wet or emulsified oil. The wet oil divides in the heat exchanger, a part passing to each battery of pipe retorts, where it passes first upward through the prewarming coils and thence downward through the main coil, leaving the battery at a temperature of 450° to 475° F. (232.2° to 246.1° C.). Four-inch asbestos-jacketed lines convey the hot oil to the inlet on each vapor separator. A regulating valve on this line maintains a back pressure on the retorts. The oil, finely sprayed downward through the tower, parts with its vapor and collects as residuum in the bottom, whence it gravitates through the jacket of the exchangers to the residuum coolers and to storage. Vapors leave the top of the tower and pass to the condensers.

The dry oil from the second pump divides and passes through two sets of exchangers connected in parallel, each feeding one battery of stills. Oil leaves the first still at 250° F. (121.1° C.), the second at 300° F. (149° C.), and the third at 375° F. (190.5° C.), and passes from the fourth at 450° F. (232.2° C.) to the heat exchangers as residuum. This residuum after leaving the exchangers is further cooled in the residuum cooler and gravitates to storage.

The vapors from each still are withdrawn from the dome and pass by means of a 6-inch vapor header to the small separator, where distillate emulsion is dropped. Thence they flow to the condenser from which they flow as condensate to storage.

The condensed vapors from pipe retorts and boiler stills carry much of this emulsion, which seemingly is caused by the small size of the vapor lines and the condenser. The emulsion, which settles in the first-run distillate storage tank, is rerun in the steam stills, as is also such part of the distillate which it is desired to fractionate.

RERUNNING PLANT.

The product to be rerun is forced by a Worthington duplex pump, 5¼ by 4¾ by 5 inches, through the tubes of the exchanger into the first still. A similar pump forces the residue from each still into the following one, and the steam-still "bottom" from the last still is pumped to one of the wooden box condensers, whence it gravitates through the tail house to storage. Each still is heated by live steam

and maintained at a higher temperature than the preceding one, so that three distinct vapor fractions are evolved.

The vapor fraction from each still passes through the dome to the dephlegmators where heavy distillates are condensed and return to the stills for evaporation. The lighter vapors are condensed in the condensers and gravitate to the coolers and storage.

The character of the oil handled in the stills and retorts is shown in the table following:

Character of oil handled in stills and retorts of Brea plant.

OIL IN PIPE RETORTS.

Sample.	Gravity of crude oil run.		Water in crude.	Distillate made.	Gravity of distillate.	
	° B.	Specific gravity.			° B.	Specific gravity.
			Per cent.	*Per cent.*		
1	20	0.934	14.4	12.0	46.0	0.7970
2	20.1	.9332	11.2	11.6	49.0	.7840
3	20.3	.9325	8.8	14.0	48.0	.7885

OIL IN BOILER STILLS.

1	20.3	0.932	1.0	12.9	50.0	0.7795
2	19.6	.936	3.0	10.9	49.0	.7840
3	19.8	.935	1.8	10.4	49.0	.7840

Sample 1 from the boiler stills was taken from a storage tank, the bottom of which contained oil carrying 22 per cent of water and base sediment.

CAPACITY.

The following tabulation represents a 90 days' record of the oil handled, the products made, and the fuel consumed in the entire crude plant:

Oil handled, products made, and fuel consumed during 90 days' operation of Brea plant.

		Barrels.
Dry crude run in boiler stills		334,000
Wet crude run in pipe retorts		174,000
Total crude run		508,000
Distillate made		78,900
Residuum made		405,000
Water dehydrated		15,630
Loss, leaks, and light gases		8,470
Total		508,000
Oil fuel used	barrels	11,400
Gas fuel used	cubic feet	21,495,000

The figures given above represent an average daily capacity of about 3,700 barrels for the boiler stills and 1,600 barrels for the retorts.

FUEL CONSUMPTION.

If the oil fuel has a gravity of 16° B. (specific gravity, 0.9595), it will have a calorific value of 6,323,180 British thermal units (1,593,000 calories) per barrel, and the gas can be assumed to have a value of 1,000 British thermal units (252 calories) per cubic foot. The plant record presented above shows that for each barrel of oil topped 183,939 British thermal units (46,355 calories) of heat is used, a fuel consumption of 2.9 per cent of the crude run.

COST OF OPERATION.

The total daily labor charge against the plant is represented by the following pay roll:

Daily pay roll at Brea plant.

1 stillman, 2 shifts, at 3.50 each	$7.00
1 engineer, 2 shifts, at $3.50 each	7.00
1 helper, 2 shifts, at $2.75 each	5.50
1 steam stillman, 2 shifts, at $3 each	6.00
Office force and superintendent	15.00
Total	40.50

FIRE HAZARD.

Fires frequently start at the boiler stills. Loose stay bolts and leaky flues are generally responsible, and fires are unavoidable and often dangerous on account of the large quantity of oil in each still at any time. The pipe retorts are occasionally perforated at the bends from the sediment contained in the oil, and the lower tubes are sometimes split from overheating. The fires resulting are not serious and can be easily controlled.

REPAIRS.

Both boiler stills and pipe retorts have become coked, seemingly as a result of too rapid cooling during a shutdown. Repairs are expensive so that replacement of the coked tubes of retorts is often cheaper than repairs.

In general, the retorts give little trouble though handling a very bad oil, whereas the boiler stills require constant watching.

CHANGES AND IMPROVEMENTS POSSIBLE.

This plan can not be considered as a type to be improved. It is constructed of discarded or idle material accumulated in operation and necessarily has limitations. However, its operation shows the undesirability of using boilers for stills, and indicates the results that can be accomplished in treating wet and dirty oil in pipe retorts.

The heat exchangers are much too small and could better be operated in series. It should be possible to recover considerably more heat from the residuum and dispense with the coolers at present used. If the exchangers were operated in series, the quantity of oil treated in any one apparatus would be positive and not variable as when headers are used.

The condensers are also inadequate and are open to the same objection regarding headers.

In general, experience tends to prove that the use of headers is objectionable, and, if the oil thus divided is to be heated by some apparatus directly fired, their use is positively dangerous, because no assurance can be had that the oil is circulating properly. A small obstruction in one tube will divert the flow and the burnt or coked tube resulting will be the first sign of trouble. Practically, the safe course is to give the oil one path of flow; then any obstruction retarding it is instantly indicated by an increased pump pressure.

I. W. FUQUA PLANT.

GENERAL DESCRIPTION.

During 1911 and 1912, a producing company at Fellows, Kern County, constructed a large topping plant designed by I. W. Fuqua, for dehydrating and topping its production from the Midway fields in California. The plant has a normal daily capacity for removing a 15 per cent vapor cut from 20,000 barrels of dry oil when working at a temperature of 350° to 400° F. (176.6° to 204.4° C.). When the oil contains much water or emulsion this capacity is considerably reduced.

Prior to the construction of the plant the production had been piped to Port Harford and thence shipped by boat to a large refinery at Oleum on San Francisco Bay. The large water content made this method impracticable without preliminary treatment of the oil.

After the topping plant had begun work the company continued the same method of shipment, the residual oil and distillate being

pumped separately through the lines. Considerable fuel oil was also shipped from the field by cars.

The plant is divided into three batteries each consisting of eight independent heaters. Each battery of heaters discharges into a single vertical separating chamber, whence the vapors removed are led by a 12½-inch header, common to the three batteries, to a group of 25 box condensers.

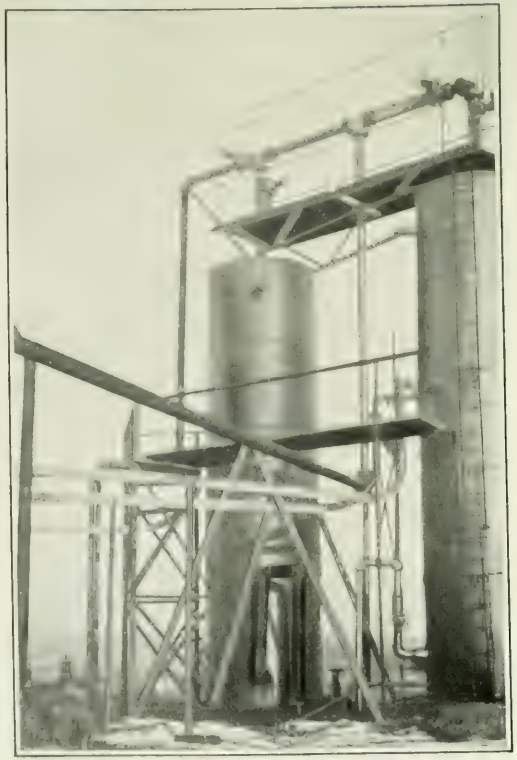
A 4-inch header collects the distillates from each box and leads them to small settling tanks where the water content is removed. They then gravitate to a 55,000-barrel insulated storage tank. Four cooling towers of the type shown in Plate XIX, *B*, are used for cooling the water from the condensers. Two jacketed line heat exchangers 1,540 feet long composed of 6-inch pipe within 12½-inch pipe, heat incoming crude in exchange with the outgoing residuum. From the heat exchangers the crude flows through two horizontal cylindrical water traps in series, then around the tubes of two cylindrical tubular steam oil warmers in parallel into a third water trap, and on to the heaters. Considerable dehydration is accomplished in these traps and warmers.

A rerunning plant consisting of 3 heaters, 3 separating chambers, and 16 condenser boxes is provided. Fractionation of the distillates is accomplished by running it through these heaters in series. Each heater supplies a separator, and the condensers are apportioned to each separator as the volumes of vapors of each fraction require.

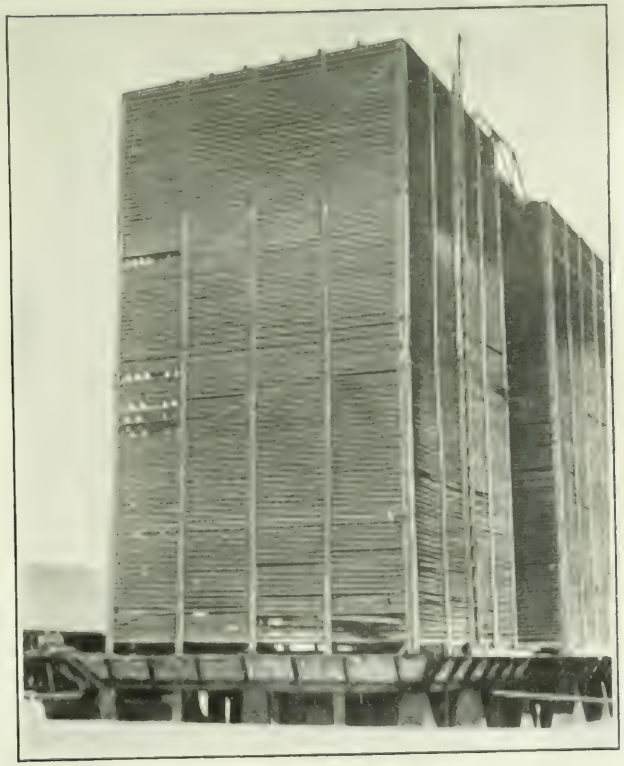
DETAILED DESCRIPTION OF APPARATUS.

HEATERS.

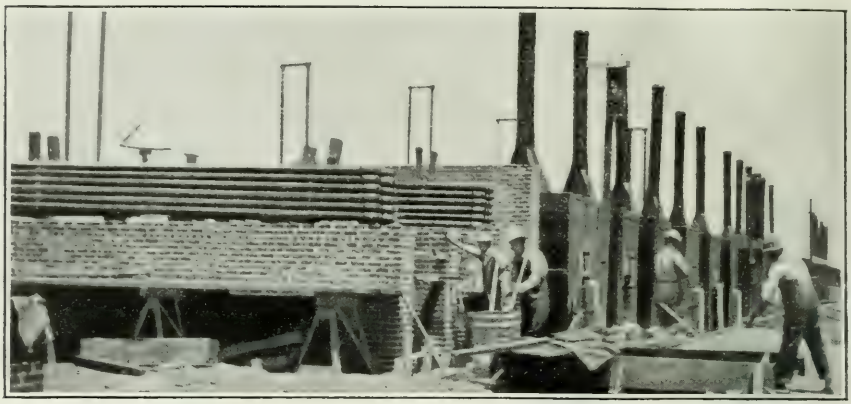
The heaters (fig. 6) are all alike, and each contains 56 joints of 3-inch pipe 20 feet 9 inches long arranged in four groups or coils of 14 each. Two groups are placed directly over the fire chamber, and the other two are supported above the arch which acts as a baffle for the flue gases. The pipes in each group are connected end to end by 3-inch tees and nipples. The open end of each tee is fitted with a 3-inch plug, permitting the inspection and cleaning of any pipe. Oil enters the upper right coil at the top, flowing back and forth and downward to the top of the upper left coil and similarly downward through the upper and lower left coils to the bottom of the lower right coil, leaving the heater at the top of this coil. In addition to the coils of oil, a small coil is provided in each heater for superheating the steam used in the separators.



A. SEPARATING TOWERS. BREA REFINERY. NOTE OVERSHOT IN THE RESIDIUM PIPING TO MAINTAIN CONSTANT LEVEL IN THE TOWER.

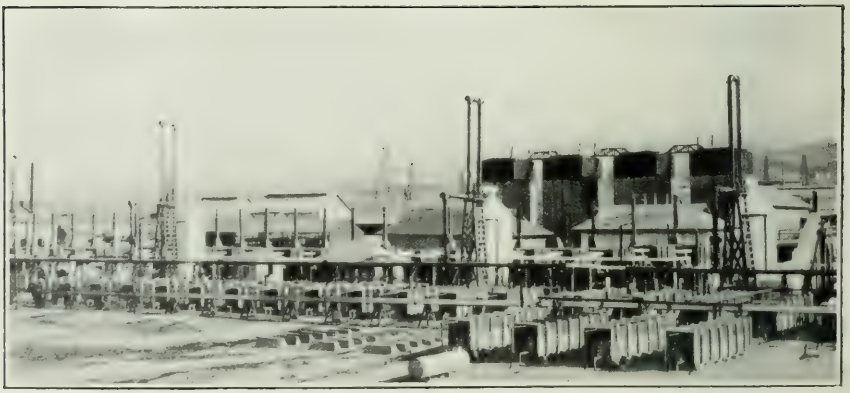


B. WATER COOLING TOWERS. I. W. FUQUA'S PLANT



A. BATTERY OF RETORTS DURING CONSTRUCTION. FUQUA'S PLANT.

B. FORWARD VIEW OF RETORTS SHOWING ONE WITH COIL REMOVED FOR REPAIR. FUQUA'S PLANT.



C. GENERAL VIEW OF FUQUA'S PLANT. NOTE OVERSHOT IN THE VAPOR LINES.

These coils are completely inclosed by the furnace brickwork consisting of walls 1½ feet thick, the inner course being fire brick. The lower coils are placed 3 feet above the furnace floor, forming a combustion chamber 3 by 3 by 21 feet, and the arch above forces the gases to make two passes over the coils before reaching the stack. Steel shapes embedded in the walls carry the coils. Plate XX, *A* and

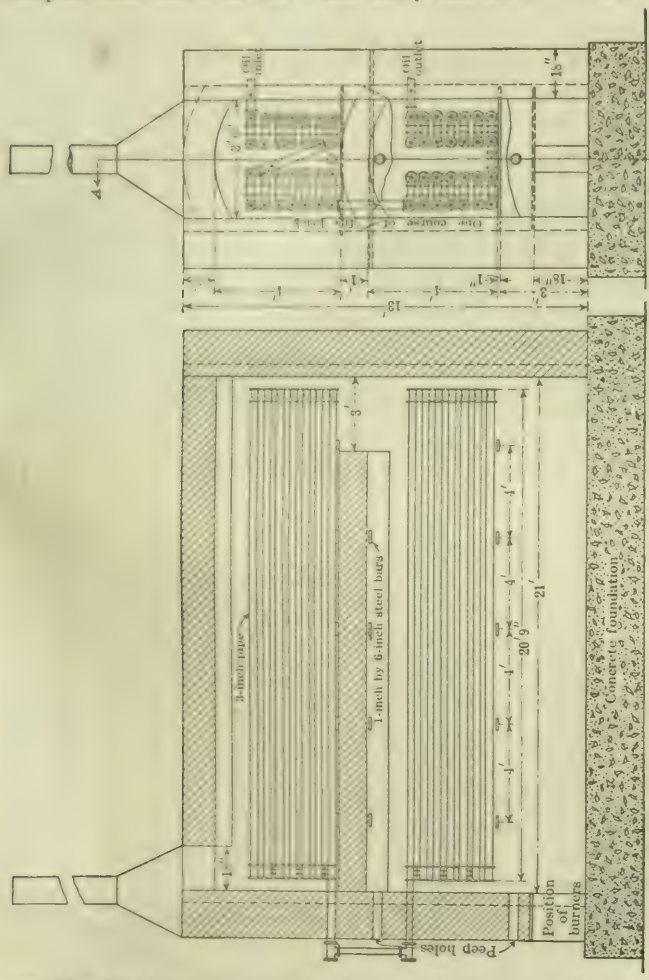


FIGURE 6.—Crude-oil heaters, I. W. Fuqua's topping plant, Fellows, Cal.

B, shows the heaters in course of construction, and Plate XX, *C*, shows a general view of the plant.

SEPARATORS.

The separators each consist of a vertical cylindrical steel shell 9 feet in diameter by 20 feet high, having conical shaped ends. The top is fitted with a 12½-inch flange for the vapor take-off, and the bottom with a 6-inch flange where superheated steam may be admitted. Within this shell five circular baffles 6 feet in diameter

are supported in a horizontal position at equal intervals over each other. Each baffle is perforated with 100 2-inch holes. An umbrella-shaped deflector is suspended just below the vapor take-off.

Hot oil enters the separator near the top through an 8-inch opening, and is deflected downward, falling over and through each baffle, collecting finally at the bottom whence it is withdrawn as residuum by an 8-inch pipe placed 4 feet above the lower edge of shell. Vapors separated from the oil in its downward course leave at the top above the deflector.

The entire shell is heavily insulated with an asbestos covering, and manholes are provided for the inspection of the interior. Figures 7 and 8 show the details of this apparatus. Plate XXI shows the separator and the vapor and distillate piping.

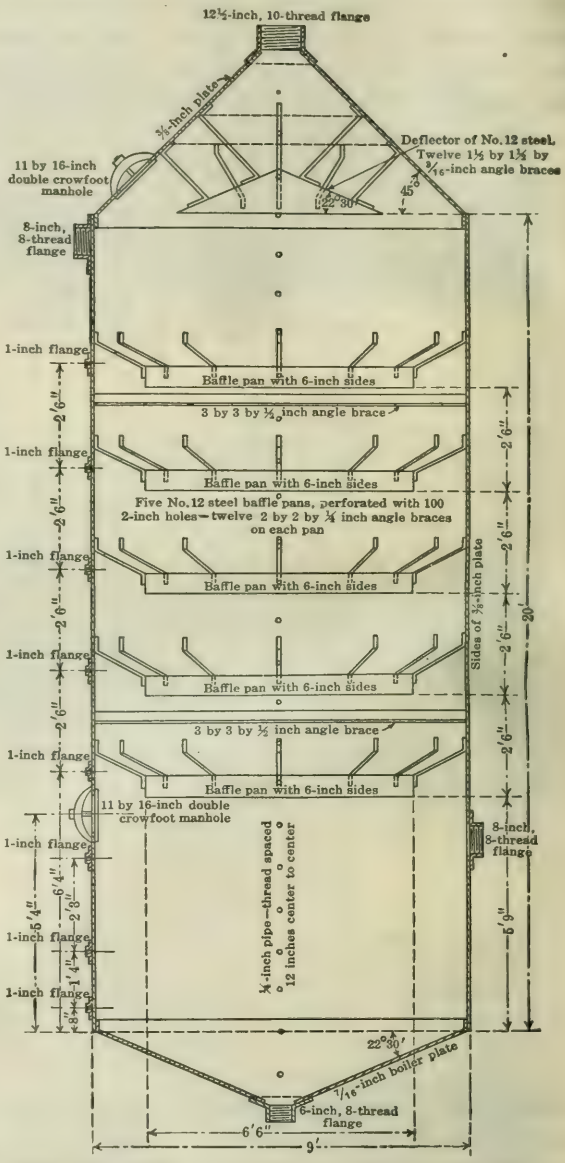
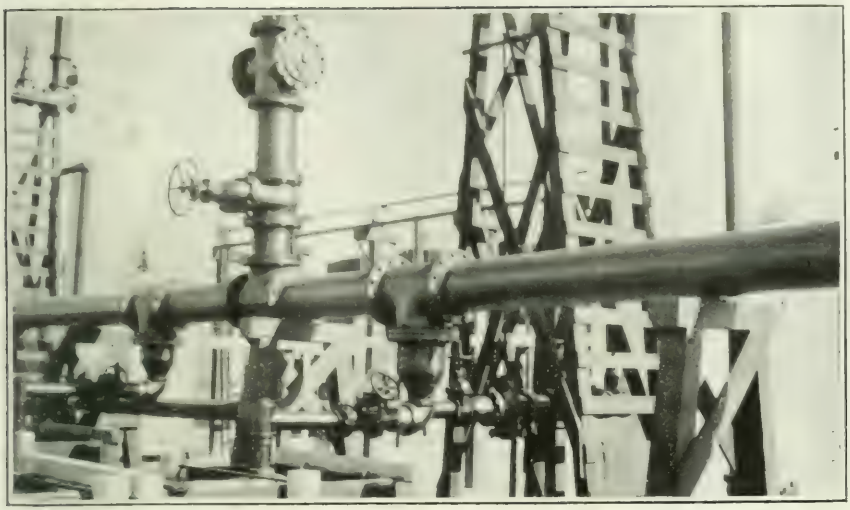


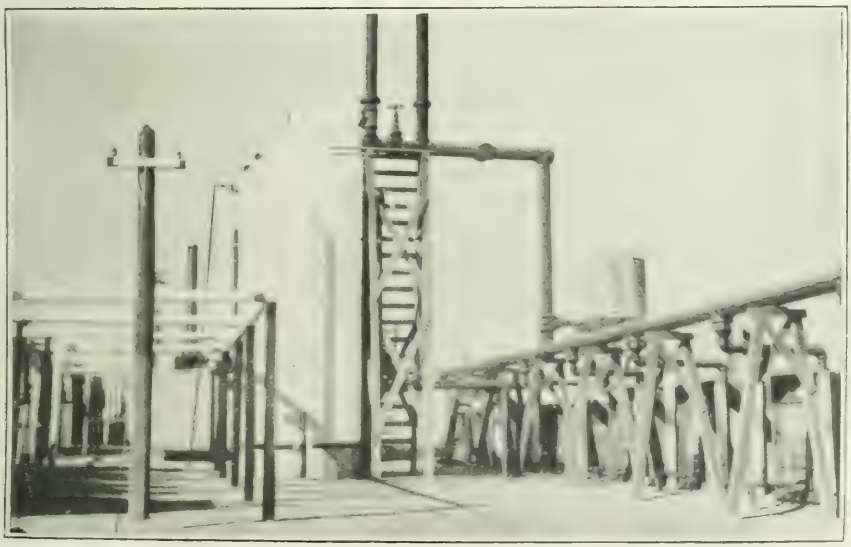
FIGURE 7.—Elevation of separating tower, Fuqua topping plant.

CONDENSERS.

The condensers are of the open submerged type and are built in three different sizes. In general, each consists of a series of pipe



A. VAPOR HEADER FEEDING THE CONDENSER BOXES. FUQUA'S PLANT



B. VIEW OF SEPARATING TOWERS AND HOT OIL AND VAPOR PIPING. FUQUA'S PLANT.

coils of diminishing sizes composed of joints of pipe connected end to end by 90 elbows and nipples. The vapors enter the top and largest coil, leaving from the bottom coil as distillate. The cooling water enters the box container at the bottom on one end and leaves at the top on the other, roughly countercurrent to the flow of the vapors. The boxes are constructed of redwood planking, 2 by 12 inches, placed over Oregon pine framing, 4 by 4 inches, stayed with ¾-inch rods. Figure 9 shows each size and the number of boxes of each size in use. A bill of materials follows. Plate XXI, *A* and *B*, shows the condensers and a close view of the vapor header connecting them and Plate XIX, *B*, (p. 48) shows the type of cooling tower used.

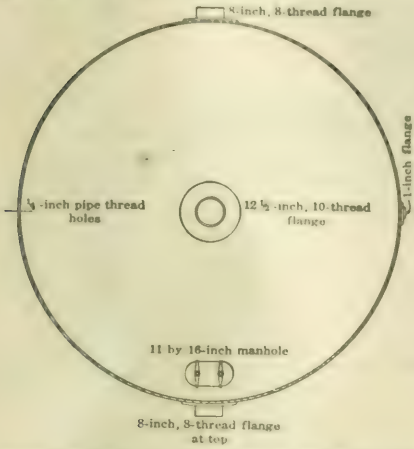


FIGURE 8.—Plan of separating tower, Fuqua topping plant.

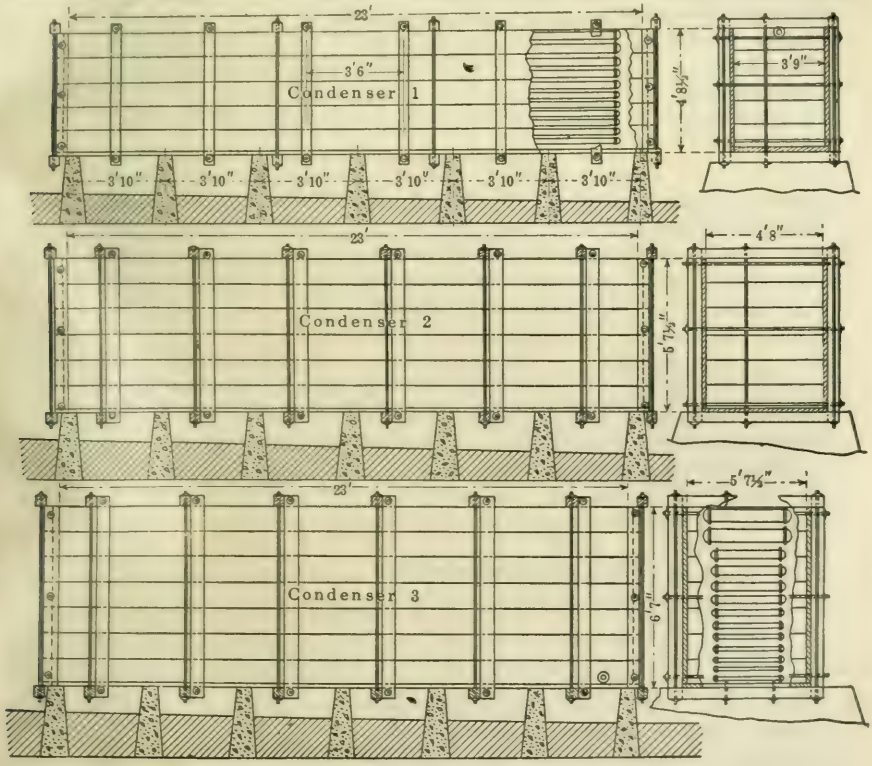


FIGURE 9.—Details of condensers, Fuqua topping plant.

Data on material required for condensers shown in figure 9.

CONDENSER 1.

Redwood planks, tank stock, 2 by 12 inches by 24 feet	14
Pine timbers, 4 by 4 inches by 5 feet 8½ inches	10
Pine timbers, 4 by 4 inches by 5 feet 4 inches	12
Pine timbers, 4 by 4 inches by 4 feet 7 inches	4
Redwood planks, tank stock, 2 by 12 inches by 3 feet 8 inches	10
Joints, 4-inch pipe	4
Joints, 3-inch pipe	6
Joints, 2-inch pipe	13
Nipples, 4 by 12 inches	3
Nipples, 3 by 14 inches	6
Nipples, 2 by 16 inches	13
Concrete piers	7
Bolts, ¾ inch by 5 feet, with nuts	18
Bolts, ¾ inch by 5 feet 6 inches, with nuts	12
O. G. washers, for ¾-inch bolts	60
Ells, 4-inch	7
Ells, 3-inch	12
Ells, 2-inch	26
Swage, 4 by 3 inches	1
Swage, 3 by 2 inches	1
Kewanee union, 2-inch	1
Flanges, 2-inch	3
Plugs, 2-inch	2
Flange, 3-inch	1
Flange, 4-inch	1

CONDENSER 2.

Redwood planks, tank stock, 2 by 12 inches by 24 feet	17
Redwood planks, tank stock, 2 by 12 inches by 4 feet 8½ inches	10
Pine timbers, 4 by 4 inches by 5 feet 8 inches	16
Pine timbers, 6 by 6 inches by 5 feet 5½ inches	4
Pine timbers, 6 by 6 inches by 6 feet 5 inches	12
Joints, 6-inch pipe	2
Joints, 4-inch pipe	4
Joints, 3-inch pipe	6
Joints, 2-inch pipe	13
Nipple, 6 by 12 inches	1
Nipples, 4 by 14 inches	3
Nipples, 3 by 16 inches	6
Nipples, 2 by 18 inches	13
Concrete piers	7
Bolts, ¾ inch by 6 feet 4 inches, with nuts	38
O. G. washers, for ¾-inch bolts	76
Ells, 6-inch	3
Ells, 4-inch	7
Ells, 3-inch	12
Ells, 2-inch	26
Swage, 6 by 4 inches	1
Swage, 4 by 3 inches	1
Swage, 3 by 2 inches	1
Kewanee union, 2-inch	1

Flanges, 2-inch	3
Plugs, 2-inch	2
Flange, 3-inch	1
Flange, 4-inch	1

CONDENSER 3.

Redwood planks, tank stock, 2 by 12 inches by 24 feet	19
Redwood planks, tank stock, 2 by 12 inches by 4 feet 8½ inches	14
Pine timbers, 6 by 6 inches by 6 feet 5 inches	4
Pine timbers, 6 by 6 inches by 7 feet 6 inches	12
Pine timbers, 4 by 4 inches by 5 feet 8 inches	16
Joints, 6-inch pipe	4
Joints, 4-inch pipe	4
Joints, 3-inch pipe	6
Joints, 2-inch pipe	15
Nipples, 6 by 12 inches	3
Nipples, 4 by 14 inches	3
Nipples, 3 by 16 inches	6
Nipples, 2 by 18 inches	15
Concrete piers	7
Bolts, ¾ inch by 6 feet 4 inches, with nuts	16
Bolts, ¾ inch by 7 feet 4 inches, with nuts	20
Ells, 6-inch	7
Ells, 4-inch	7
Ells, 3-inch	12
Ells, 2-inch	30
Swage, 6 by 4 inches	1
Swage, 4 by 3 inches	1
Swage, 3 by 2 inches	1
Kewanee union, 2-inch	1
Flanges, 2-inch	3
Plugs, 2-inch	2
Flange, 3-inch	1
Flange, 4-inch	1

WATER TRAPS.

The water traps before mentioned are horizontal cylinders placed in the oil line. Oil enters at one end on top and leaves at the other end on top, and the contained water settles to the bottom, owing to the diminished velocity of the fluid within the trap.

STEAM OIL WARMERS.

The steam oil-warmers each consist of a horizontal cylindrical shell about 20 feet long and 6 feet in diameter fitted with removable flanged convex heads. About 2 feet from each head, within the shell, are placed vertical tube sheets, into which 366 1½-inch boiler tubes 16 feet 4 inches long are expanded. The manifolds thus formed at either end are fitted with horizontal baffles, so that the liquid within the tubes has to make three passes in its course through the apparatus. Oil enters at the bottom of one manifold and leaves

at the top of the other after being heated by the superheated steam surrounding the tubes. The steam enters at the top over the tubes near one end, and, by means of a horizontal baffle, makes two passes over the tubes, leaving at the bottom. Exhaust steam from an adjacent plant supplies the steam used in these warmers, and a superheater constructed similar to the oil heaters supplies the neces-

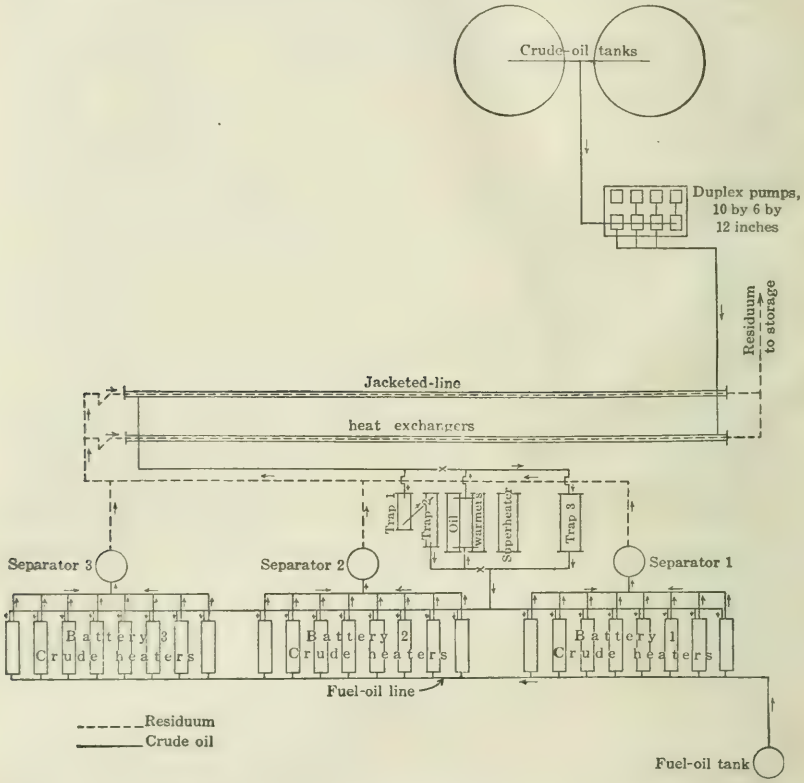
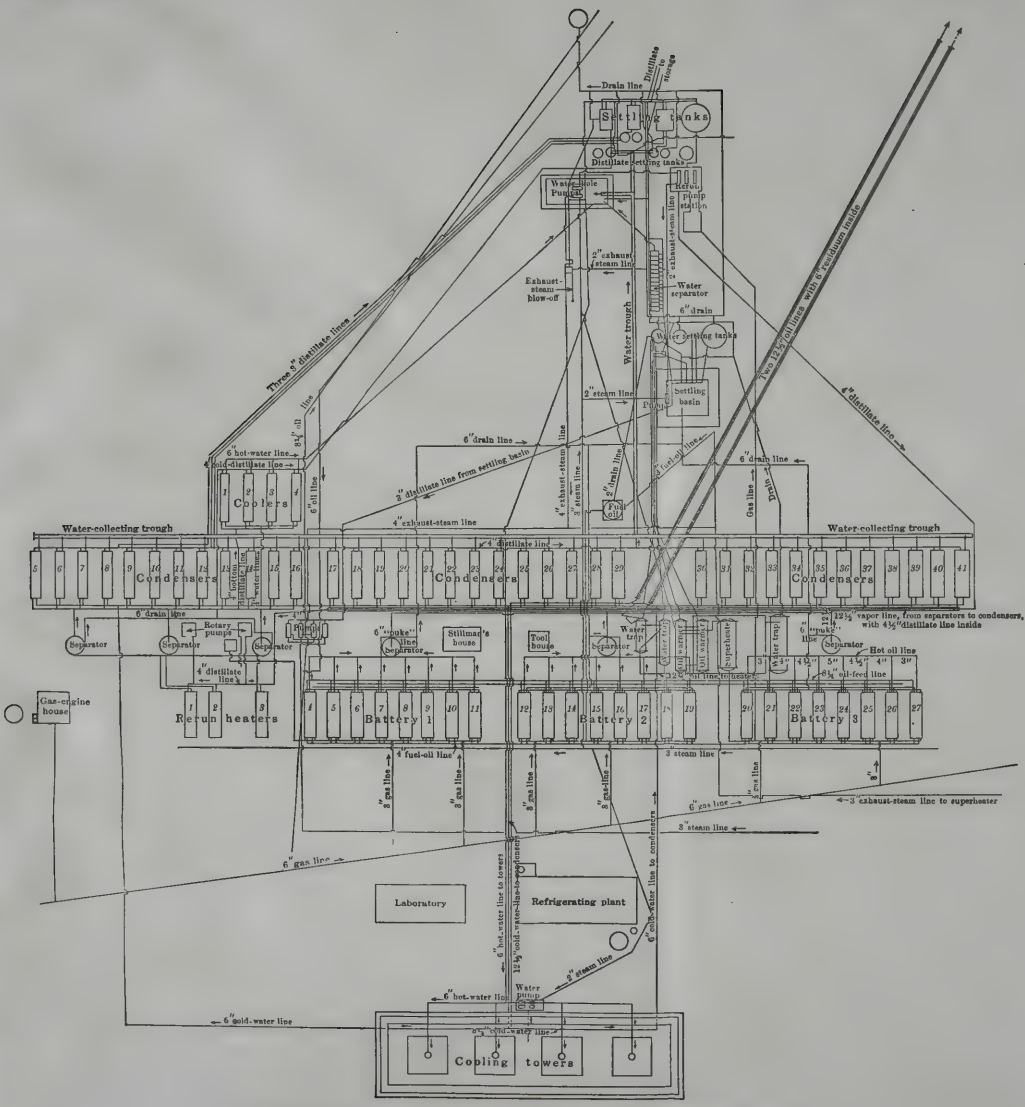


FIGURE 10.—Crude oil and residuum flow sheet, Fuqua topping plant.

sary superheat. Manholes are provided in the water traps and oil warmers for inspection and cleaning. Plate XXII shows a general plan of the topping plant.

OPERATION.

Figure 10 shows the flow of the crude oil and residuum through the plant. The crude oil is pumped by four Worthington duplex pumps, 10 by 6 by 12 inches, through the jacketed line heat exchangers, being heated by the outgoing residuum contained in the 6-inch pipes. The 6-inch pipes enter the 12½-inch pipes through stuffing boxes, and suitable swing connections are provided to permit free movement of both pipes. From the exchangers the crude



GENERAL LAYOUT, FUQUA TOPPING PLANT. FELLOWS, CAL.

at about 165° F. (74° C.) enters the two horizontal cylindrical tanks in series; there a part of the water settles out and is drained to a sump hole. The oil then flows through the tubes of the oil warmers in parallel, receiving further heat from the superheated exhaust steam, and thence flows into the last water trap, where more of its water content is dropped; thence it passes to the header supplying the heaters. Oil enters the heaters at about 185° F. (85° C.) and passes through the tubes as previously described, being heated to the required temperature by the fire and gases from the combustion chambers. Each battery of eight heaters discharges into a 5-inch header which leads the hot oil to the separating chamber for that battery. The residual oil collecting at the bottom of this chamber gravitates through the 6-inch jacketed line heat exchanger to storage, being cooled by the incoming crude. This residuum is marketed as fuel oil, and its quality can be fixed by regulating the rate of fire and feed. Plate XXIII shows the vapor and distillate flow.

The vapors, separated from the hot oil as it percolates through the baffles, pass through 12½-inch vapor take-off lines terminating in a single 12½-inch vapor line supplying the condensers. Bottom steam superheated to about 310° F. (154.5° C.) is injected in the separators, where it assists in lifting the vapors from the oil. Two 10-inch vertical standpipes 20 feet high, joined at their top by two ells and a nipple, are placed in each vapor take-off line. A valve between them permits the operator to force the vapors over the top in traveling to the condensers. Heavy distillates mechanically entrained, which tend to discolor the product, are thus returned to the separators. This construction is shown in Plates XXI, *B*, (p. 50) and XXIV, *A*.

The vapors condensed and cooled by the cooling water surrounding the condenser pipes are collected as condensate by a 4-inch distillate line and pass to several small settling tanks, where the water contained is automatically separated and returned to the water hole supplying the cooling-water pumps.

RERUNNING PLANT.

From the settling tanks a part of the distillate is pumped to the rerunning plant for fractionation into different products, and the remainder flows by gravity to storage for shipment. Distillate enters the plant through a 4-inch line within the 12½-inch vapor header, being heated by the vapors passing to the condensers. This line discharges into the first separator, and the distillate usually acquires enough heat from the exchanger to vaporize the first fraction. If this heat is insufficient, a by-pass connected to the first heater allows the distillate to pass through that heater. The residue from the

first separator is pumped through the second heater to the second separator, where a second vapor fraction is removed. The remaining distillate passes through the third heater to the third separator, where a final vapor cut is separated. The bottom distillate from this separator is cooled in a box condenser and gravitates to storage.

The heaters are fired with oil or gas, and the construction of all apparatus in the rerunning plant is identical with that of the crude set.

DISTILLATE SAMPLE.

The table shown below gives an average sample of distillate from the plant and the resulting fractionation accomplished in rerunning.

First-run distillate.

Gravity, 44.5° B. (0.804).
24 per cent of 60° B. (0.739).
8 per cent of 50° B. (0.779).
68 per cent of 38.3° B. (0.833).

First fraction.

Gravity, 56.5° B. (0.752).
80 per cent of 60.1° B. (0.738).
20 per cent of 38.1° B. (0.834).

Second fraction.

Gravity, 46.3° B. (0.795).
2 per cent of 60° B. (0.739).
64 per cent of 50° B. (0.779).
34 per cent of 38.2° B. (0.834).

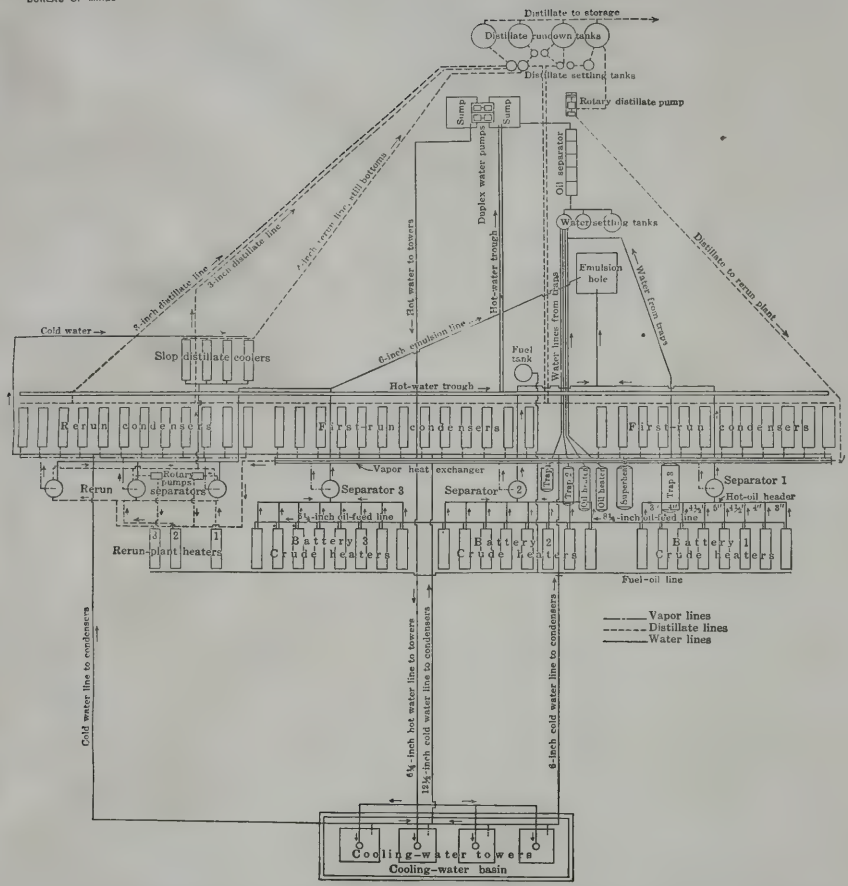
Third fraction.

Gravity, 42.4° B. (0.813).
18 per cent of 50° B. (0.779).
82 per cent of 40° B. (0.825).

Bottom distillate.

Gravity, 33.2° B. (0.858).
10 per cent of 40° B. (0.825).
90 per cent of 32.4° B. (0.862).

The results of a typical laboratory fractionation made by the refinery chemist of the first-run distillate having a gravity of 43.5° B. (specific gravity, 0.808) follow. The fractionation was made in a 2,000-c. c. flask, 1,250 c. c. of distillate being used, and each 2 per cent fraction being tested. The rate of distillation was two drops per second, while the condenser was maintained at a temperature of 70° F. (22.2° C.), and with a room temperature of 60.0° F. (15.6° C.).



FLOW CHART FOR VAPOR DISTILLATES AND COOLING WATER. FUQUA TOPPING PLANT, FELLOWS CAL. — - — VAPOR LINES, - - - - - DISTILLATE LINES, ——— WATER LINES.

Results of laboratory fractionation of first-run distillate, I. W. Fuqua's plant.

Temperatures.		Per cent.	Gravity.		Product.
°F.	°C.		°B.	Specific gravity.	
Amount distilled at 84 a to 154	28 to 68	2	74.2	0.688	20 per cent of 60° B. (0.739).
to 168	to 75	4	65.8	.717	
to 174	to 78.85	6	63.3	.726	
to 180	to 82.2	8	60.5	.737	
to 183	to 83.85	10	59.9	.739	
to 198	to 92.2	12	56.8	.751	
to 212	to 100	14	56.2	.753	
to 220	to 104.5	16	55.5	.756	
to 232	to 111.1	18	54.3	.761	
to 240	to 115.5	20	53.8	.763	24 per cent of 50° B. (0.779).
to 248	to 120	22	53.3	.765	
to 258	to 125.5	24	52.9	.767	
to 266	to 130	26	52.6	.768	
to 270	to 132.2	28	51.5	.773	
to 278	to 136.6	30	50.9	.775	
to 284	to 140	32	50.1	.779	
to 290	to 143.3	34	49.7	.780	
to 292	to 144.5	36	49.0	.784	
to 297	to 147.2	38	48.4	.786	
to 300	to 149	40	47.9	.789	
to 306	to 152.2	42	47.2	.791	
to 310	to 154.5	44	46.6	.794	
to 318	to 159	46	46.0	.797	
to 320	to 160	48	45.2	.800	
to 326	to 163.3	50	44.0	.806	
to 330	to 165.6	52	43.9	.807	24 per cent of 42.1° B. (0.815).
to 336	to 168.9	54	43.0	.811	
to 340	to 171.1	56	42.1	.815	
to 348	to 175.6	58	41.8	.816	
to 352	to 177.8	60	40.9	.821	
to 358	to 181.1	62	40.5	.822	
to 362	to 183.3	64	39.9	.825	
to 366	to 185.6	66	39.2	.828	
to 370	to 187.8	68	38.6	.831	
to 376	to 191.1	70	37.7	.836	32 per cent of 29.4° B. (0.879).
		72	37.3	.838	
		74	36.7	.840	
to 382	to 194.6	76	36.3	.842	
		78	36.0	.844	
to 400	to 204.5	80	35.3	.847	
Final boiling point 450 b	232.2				

a Initial boiling point. b Estimated.

The results of three additional laboratory distillations in an Engler flask, and of one distillation made in a small experimental still, are given to better acquaint the reader with the quality of oil handled.

Results of distillations of oil handled in I. W. Fuqua's plant.

DISTILLATION MADE APRIL 1, 1913.

[Gravity of oil, 19.2° B. (specific gravity, 0.938); 2500 c. c., tested in Engler flask, water 3 per cent.]

Per cent.	Gravity.		Average gravity.	
	° B.	Specific gravity.	° B.	Specific gravity.
1	52.1	0.770	52.1	0.770
2	49.9	.780	50.5	.777
3	46.7	.793	49.2	.783
4	43.6	.808	47.8	.789
5	41.9	.816	46.6	.794
6	40.3	.823	45.6	.798
7	38.9	.830	44.6	.803
8	37.6	.836	43.7	.807
9	36.0	.844	42.8	.811
Residue			16.8	.954

Results of distillations of oil handled in I. W. Fuqua's plant—Continued.

DISTILLATION MADE APRIL 13, 1913.

[Gravity of oil, 22.7° B. (specific gravity, 0.918); 2500 c. c., tested in Engler flask; no water.]

Per cent.	Gravity.		Average gravity.	
	° B.	Specific gravity.	° B.	Specific gravity.
2	65.4	0.719	65.4	0.719
4	59.4	.741	62.4	.730
6	55.2	.757	60.0	.739
8	52.0	.771	58.0	.747
10	48.9	.784	57.8	.747
12	46.8	.793	52.6	.768
14	45.3	.800	53.2	.766
16	43.6	.808	52.1	.770
18	42.2	.814	50.9	.775
20	40.1	.824	49.9	.780
22	38.3	.833	49.4	.782
24	36.6	.841	48.8	.784
Residue			16.5	.956

DISTILLATION MADE APRIL 25, 1913.

[Gravity of oil, 22.7° B. (specific gravity, 0.918; 2500 c. c., tested in Engler flask; no water.]

Per cent.	Gravity.		Average gravity.	
	° B.	Specific gravity.	° B.	Specific gravity.
2 [a]	68.6	0.707	68.6	0.707
4 [a]	59.4	.741	64.0	.724
6 [a]	54.3	.761	60.8	.738
8	51.2	.774	58.3	.745
10	49.4	.782	56.5	.752
12	47.5	.790	55.0	.758
14	46.1	.796	53.8	.763
16	43.9	.807	52.5	.769
18	41.8	.816	51.3	.773
20	39.9	.825	50.2	.778
22	38.4	.832	49.1	.783
24	36.8	.840	48.1	.788
26	35.2	.848	47.1	.792
Residue			16.2	.958

[a] Gasoline.

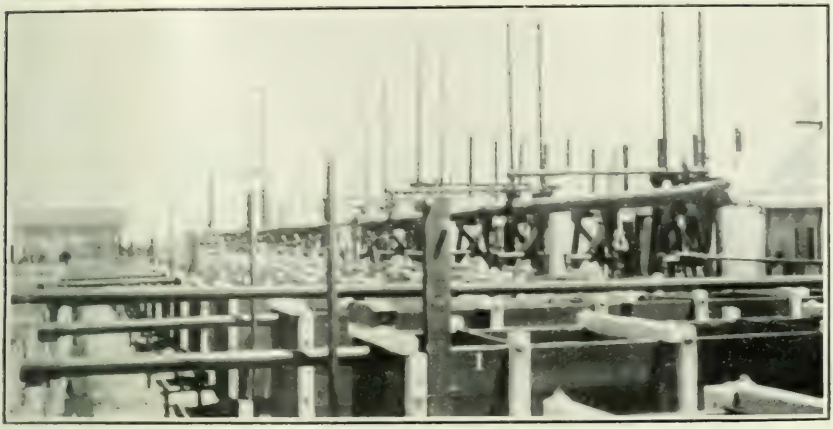
DISTILLATION MADE NOVEMBER 21, 1916.

[Gravity of oil, 17° B.; 5000 c. c., fractionated in small experimental stills; water 25.5 per cent; gravity of dehydrated sample at 60° F. (15.6° C.), 19.2° B. (specific gravity, 0.938).]

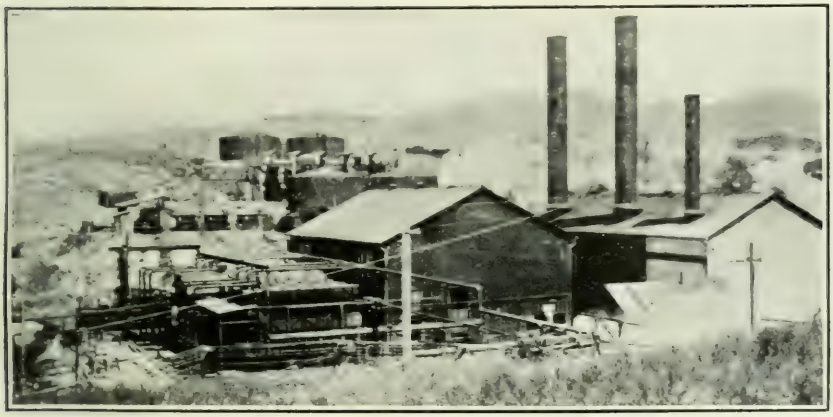
Fraction per cent.	Gravity.	
	° B.	Specific gravity.
2.6	60.1	0.738
3.0	49.8	.780
3.5	40.1	.824
Residue	16.2	.958

COST OF OPERATION.

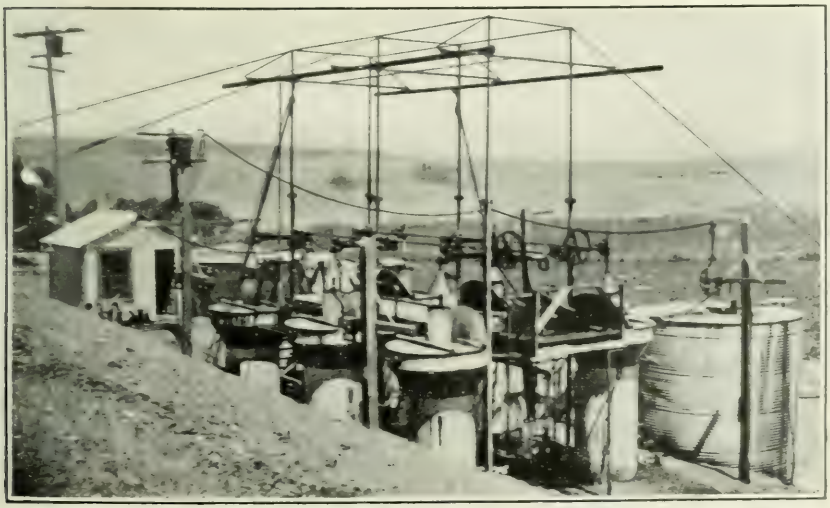
Table 11 following gives the cost of operation and repair of the plant from April, 1913, to November, 1915. With the plant running at normal capacity the cost of producing the distillate was about 8.5 cents a barrel, and the cost of treating the crude was about 0.9 cent a barrel.



A. VIEW OF CONDENSER BOXES SHOWING WATER DISCHARGE. FUQUA'S PLANT.



B. GENERAL VIEW OF E. I. DYERS TOPPING PLANT. NOTE DEHYDRATER IN BACKGROUND.



C. ELECTRICAL DEHYDRATING EQUIPMENT. DYERS TOPPING PLANT.

TABLE 11.—*Cost of refinery operation and repairs, I. W. Fuqua plant.*[a]

Date.	Labor.	Supplies.	Renewals and repairs.	Steam.	Total cost.	Total barrels topped.	Average cost per barrel.	Total crude oil run.	Average cost per barrel of crude oil run.
1913.								*Barrels.*	
April	$624.08	$77.42	$1,262.07	$169.19	$2,133.26	28,676.51	$0.074	242,546.0	$0.0087
May	927.42	122.23	584.39	591.79	2,225.83	33,264.22	.067	251,708.0	.0088
June	807.44	79.63	165.44	619.07	1,671.58	33,218.08	.050	216,935.7	.0077
July	903.82	121.49	249.16	641.10	1,915.57	30,902.72	.062	211,911.0	.0090
August	917.21	158.30	490.41	632.82	2,198.74	27,134.71	.081	210,097.0	.0100
1914.									
February	989.86	25.01	108.10	296.84	1,419.81	25,171.70	.056	234,908.7	.0060
March	1,212.52	8.53	145.12	258.02	1,624.19	28,777.49	.059	200,920.0	.0080
April	857.51	20.17	14.19	407.31	1,299.18	39,781.74	.033	286,941.0	.0040
May	1,076.46	22.10	534.19	499.55	2,127.30	30,946.56	.068	277,655.0	.0070
July	1,531.93	48.61	299.07	525.00	2,404.61	29,378.00	.082	250,298.0	.0090
August	1,250.09	20.38	186.73	432.50	1,889.70	22,445.67	.084	346,959.0	.0054
September	1,141.96	17.72	110.28	422.27	1,692.23	22,482.00	.075	446,909.0	.0038
October	1,266.91	11.16	176.09	354.22	1,808.38	21,563.70	.083	282,076.0	.0060
November	1,119.83	15.62	71.56	499.70	1,706.71	22,700.90	.075	182,591.3	.0090
1915.									
January	1,724.96	13.05	303.22	503.57	2,544.80	21,799.13	.112	178,497.0	.0140
February	1,333.00	27.50	74.72	499.51	1,934.73	15,712.79	.123	133,593.0	.0140
March	1,256.20	3.29	73.14	600.45	1,933.08	23,210.00	.080	211,455.0	.0090
April	1,489.07	8.00	147.43	631.70	2,276.20	32,966.30	.069	229,716.5	.0099
May	1,555.05	.....	371.19	576.47	2,502.71	23,551.65	.106	245,906.5	.0100
June	1,507.42	12.55	114.75	642.70	2,277.42	29,813.42	.076	223,977.0	.0100
July	1,548.46	10.34	169.09	529.12	2,257.01	26,411.20	.085	256,184.0	.0080
August	1,934.96	11.13	397.11	671.25	3,014.45	26,202.11	.115	251,095.0	.0120
September	1,607.18	17.27	160.74	456.77	2,241.96	22,047.12	.101	241,328.8	.0090
October	1,509.78	.....	915.58	484.24	2,909.60	19,298.06	.151	204,189.2	.0140
November	1,459.18	20.34	1,248.43	553.63	3,281.58	18,922.18	.173	174,306.5	.0180
Total	31,547.30	871.84	8,372.70	12,498.79	53,290.63	657,347.96	2.141	5,992,704.3	.2303
Average per month	1,261.89	34.87	334.91	499.95	2,131.62	26,293.91	.086	239,708.2	.0092

[a] Figures of cost do not include fuel used nor refinery loss.

TABLE 12.—*Record of plant operation, I. W. Fuqua's topping plant.*

Date.	Num- of heat- ers used.	Crude.			Mud and base sedi- ment.	Distillate.					
		Oil topped.	Gravity.			Volume produced.	Gravity.		Cut.	Temperature in tank.	
		Barrels.	°*B.*	*Specific gravity.*	*Per cent.*	*Barrels.*	°*B.*	*Specific gravity.*	*Per cent.*	°*F.*	°*C.*
1916.											
Oct. 20	7	5,005	17.2	0.951	14 to 20	859.2	43.1	0.810	13.85	68	20.0
		1,197	22.6 to 23.5	0.918 to 0.913							
21	7	4,392	17.5	.950	16 to 20	725.6	43.6	.808	13.1	66	19.0
		1,137	22.7 to 23.4	918 to .913	12 to 18						
22	8	4,139	16.9	.954	16 to 20	649.0	43.5	.808	12.98	62	16.6
		862	23.2 to 23.8	.915 to 911	10 to 12						
23	8	4,209	17.3	.951	14 to 22	953.7	44.2	.805	15.08	63	17.2
		2,027	23.3 to 24.5	.914 to .907	4 to 16						
24	8	4,136	17.2	.951	16 to 28	514.0	44.2	.805	7.7	59	15.0
		495	19.1 to 23.7	.939 to .912	10 to 38						
25	8	5,076	17.0	.953	14 to 18	1,009.0	43.9	.807	15.67	60	15.6
		826	19.1 to 20.0	.939 to .934	2 to 4						
26	8	3,891	17.6	.949	14 to 18	629.0	43.9	.807	.....	57	14.0
		1,083	19.3 to 25.6	.938 to .901	2 to 12						
27	8	4,430	18.0	.946	12 to 20	860.0	43.3	.809	15.5	61	16.1
		797	22.6 to 24.6	.918 to .907	6 to 12						
28	7	3,223	18.3	.944	.....	743.0	43.3	.809	17.3	66	18.9
		1,066	21.4 to 22.7	.925 to .918	.....						
29	7	5,029	17.6	.949	14 to 18	725.0	43.5	.808	12.57	60	15.6
		740	22.5 to 23.2	.918 to .915	18 to 28						
30	7	4,282	17.4	.950	14 to 20	668.0	43.5	.808	13.2	57	13.9
		793	22.5 to 23.2	.918 to .915	22 to 29						

Date.	Number of heaters used.	Residuum.					Heaters.				Atmospheric temperature.			Temperature of condenser intake.			
		Volume produced.	Gravity.		Temperature in tank.		Temperature in.		Temperature out.		Noon.		Midnight.	Noon.		Midnight.	
1916.		*Barrels.*	°*B.*	*Specific gravity.*	°*F.*	°*C.*	°*F.*	°*C.*	°*F.*	°*C.*	°*F.*	°*C.*	°*F.*	°*F.*	°*C.*	°*F.*	°*C.*
Oct. 20	7	5,342	16.2	0.958	162	72.2	175	79.5	360	182.2	78	25.6	62	73	22.8	64	17.8
21	7	4,003	16.4	.957	162	72.2	175	79.5	360	182.2	82	27.7	63	71	21.7	66	19.0
22	8	4,331	16.1	.958	164	73.3	178	81.0	370	187.8	82	27.7	59	71	21.7	56	13.3
23	8	5,372	16.2	.958	162	72.2	175	79.5	385	196.1	69	20.7	56	60	15.6	64	17.8
24	8	4,117	16.2	.958	164	73.3	175	79.5	385	196.1	75	23.9	55	68	20.0	58	14.4
25	8	4,794	16.2	.958	170	76.6	175	79.5	400	204.5	75	23.9	56	64	17.8	60	15.6
26	8	4,345	16.5	.956	168	75.6	180	82.2	385	196.1	73	22.8	60	62	16.6	58	14.4
27	8	4,427	16.2	.958	168	75.6	175	79.5	385	196.1	80	26.6	60	68	20.0	60	15.6
28	7	3,545	16.4	.957	162	72.2	170	76.8	355	161.6	86	30.0	63	75	23.9	62	16.6
29	7	5,044	16.4	.957	162	72.2	175	79.5	355	161.6	74	23.3	53	66	18.9	58	14.4
30	7	4,407	16.5	.956	166	74.3	175	79.5	355	161.6	67	19.4	50	64	17.8	58	14.4

It will be noted that no account is taken of fuel consumed, as the company used for fuel what it considered a waste product. However, the average costs stated above should be increased by an average value for fuel consumed. If this be assumed as 1.6 per cent of crude run at a price of 50 cents a barrel, the average cost for the production of distillate would be 15.4 cents a barrel, and the average cost of treating the crude would be 1.6 cents a barrel, neglecting the refining loss.

RECORD OF PLANT PERFORMANCE.

Table 12 herewith gives a record of the performance of the plant from October 20 to 30, 1916. The ingoing and outgoing temperatures on the condensers for three days during this period are given in Table 13. It will be seen that only a part of the heaters were required to handle the oil treated; however, all the condensers were in use. Attention is called to the wide variance in the temperatures of the water discharge from these boxes. The work done by each box depended on its distance from the vapor take-off lines.

TABLE 13.—*Record of temperatures of water discharge of condenser boxes.*

OCTOBER 20, 1916.

	Temperature of water discharge.							
	9 a. m.		3 p. m.		9 p. m.		3 a. m.	
	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.
Temperature of water at tower	73	.....	74	.....	64	.....	64	.....
Box No. 3	114	45.6	122	50.0	118	47.8	104	40.0
4	95	35.0	108	42.2	102	38.9	96	35.6
5	92	33.3	98	36.6	106	41.1	98	36.6
6	94	34.4	102	38.9	96	35.6	90	32.2
7	88	31.1	96	35.6	90	32.2	86	30.0
8	92	33.3	98	36.6	90	32.2	86	30.0
9	118	47.8	123	50.6	118	47.8	106	41.1
10	123	50.5	123	50.6	126	52.2	112	44.4
11	105	40.5	112	44.4	106	41.1	96	35.6
12	142	61.1	142	61.1	136	57.8	134	56.7
13	104	40.0	116	46.7	112	44.4	102	38.9
14	142	61.1	142	61.1	138	58.9	140	60.0
15	129	53.3	138	58.9	132	55.6	128	53.3
16	119	48.3	123	50.6	124	51.1	110	43.3
17	148	64.4	141	60.6	138	58.9	132	55.6
19	97	36.1	102	38.9	96	35.6	76	24.4
19	.....	.....	140	60.0	136	57.8	108	42.2
20	98	36.6	98	36.6	94	34.5	90	32.2
21	106	41.1	106	41.1	100	37.9	98	36.6
22	110	43.3	118	47.8	116	46.7	112	44.4
23	98	36.6	96	35.6	94	34.5	90	32.2
24	144	62.2	124	51.1	126	52.2	118	47.8
25	106	41.1	114	45.6	110	43.3	108	42.2
26	147	63.9	144	62.2	142	61.1	140	60.0
27	150	65.6	154	67.8	150	65.6	146	63.3

OCTOBER 25, 1916.

Temperature of water at tower	64	.....	64	.....	68	.....	60	.....
Box No. 3	.....	.....	73	22.8	83	28.3	70	21.1
4	.....	.....	72	22.2	78	25.7	76	24.4
5	.....	.....	74	23.3	74	23.3	68	20.0
6	.....	.....	77	25.0	75	23.9	70	21.1
7	.....	.....	73	22.8	72	22.2	65	18.3
8	.....	.....	75	23.9	78	25.7	68	20.0
9	.....	.....	77	25.0	84	28.9	76	24.4
10	.....	.....	67	19.4	71	21.7	66	18.9
11	.....	.....	66	18.9	70	21.1	64	17.8
12	.....	.....	71	21.7	86	30.0	70	21.1
13	.....	.....	78	25.7	84	28.9	80	26.7
14	.....	.....	102	38.9	102	38.9	110	43.3
15	.....	.....	84	28.9	82	27.8	80	26.7
16	.....	.....	87	30.6	86	30.0	84	28.9
17	.....	.....	102	38.9	102	38.9	110	43.3
18	.....	.....	86	30.0	88	31.1	89	31.7
19	.....	.....	116	46.7	90	32.2	86	30.0
20	.....	.....	81	27.2	80	26.7	82	27.8
21	.....	.....	99	37.2	79	26.2	70	21.1
22	.....	.....	80	26.7	82	27.8	80	26.7
23	.....	.....	81	27.2	80	26.7	70	21.1
24	.....	.....	79	26.2	78	25.7	74	23.3
25	.....	.....	81	27.2	80	26.7	78	25.7
26	.....	.....	82	27.8	80	26.7	78	25.7
27	.....	.....	92	33.3	86	30.0	84	28.9

TABLE 13.—*Record of temperature of water discharge of condenser boxes*—Continued.

OCTOBER 30, 1916.

	Temperature of water discharge.							
	9 a. m.		3 p. m.		3 p. m.		3 a. m.	
	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.
Temperature of water at tower	64	.....	64	.....	58	.....	58	.....
Box No. 3	88	31.1	92	33.3	84	28.9	70	21.1
4	76	24.4	84	28.9	74	23.3	68	20.0
5	76	24.4	82	27.8	70	21.1	68	20.0
6	76	24.4	80	26.7	76	24.4	66	18.9
7	75	23.9	78	25.7	64	17.8	66	18.9
8	77	25.0	84	28.9	66	18.9	70	21.1
9	102	38.9	103	39.4	96	35.6	86	30.0
10	96	35.6	98	36.6	98	36.6	94	34.5
11	79	26.2	82	27.8	80	26.7	74	23.3
12	78	25.7	78	25.7	68	20.0	66	18.9
13	81	27.2	82	27.8	76	24.4	74	23.3
14	84	28.9	80	26.7	7[illegible]	25.7	76	24.4
15	118	47.8	112	44.4	110	43.3	108	42.2
16	92	33.3	90	32.2	88	31.1	86	30.0
17	110	43.3	108	42.2	104	40.0	102	38.9
18	108	42.2	106	41.1	104	40.0	100	37.9
19	96	35.6	102	38.9	96	35.6	92	33.3
20	86	30.0	88	31.1	84	28.9	80	26.7
21	84	28.9	86	30.0	84	28.9	80	26.7
22	86	30.0	90	32.2	86	30.0	82	27.8
23	89	31.7	94	34.5	90	32.2	86	30.0
24	88	31.1	82	27.8	80	26.7	76	24.4
25	96	35.6	115	46.1	110	43.3	108	42.2
26	92	33.3	88	31.1	84	28.9	80	26.7
27	118	47.8	122	50.0	118	47.8	110	43.3

HEAT TRANSFER.

Because of the lack of facilities for metering the flow of liquids through parts of the plant, it was difficult to obtain data for computing the rates of heat transfer obtained in the different apparatus. The use of headers also seriously handicapped these attempts, as it was evident, particularly in the condensers, that each unit did a variable amount of work.

The jacketed line heat exchangers, however, presented an opportunity to obtain a value for the heat transfer occurring under working conditions, and the daily readings on page 65, Table 14, were taken for that purpose.

TABLE 14.—*Records covering rate of heat transfer in jacketed line heat exchangers, I. W. Fuqua's topping plant.*

RECORD 1.

Date.	Crude entering plant.						Residuum leaving plant.				
	Net oil.	Per cent of moisture.	Temperature.				Amount.	Temperature.			
			Ingoing.		Outgoing.			Ingoing.		Outgoing.	
	Barrels.		*° F.*	*° C.*	*° F.*	*° C.*	*Barrels.*	*° F.*	*° C.*	*° F.*	*° C.*
.....	4,404.27	24 to 36	62	16.7	140	60.0	3,451.55	400	204.5	170	76.7
.....	5,812.18	16 to 28	56	13.3	145	62.8	4,874.33	410	210.0	175	79.4
.....	6,500.25	18 to 24	46	7.8	145	62.8	5,585.16	410	210.0	175	79.4
.....	5,777.86	18 to 28	38	3.3	145	62.8	4,936.60	410	210.0	175	79.4
.....	5,748.39	20 to 28	36	2.2	145	62.8	4,868.27	410	210.0	175	79.4
.....	6,243.37	24 to 32	38	3.3	140	60.0	5,267.65	400	204.5	170	76.7
.....	7,112.03	18 to 24	38	3.3	140	60.0	6,174.76	400	204.5	170	76.7
.....	6,846.86	20 to 28	38	3.3	140	60.0	6,024.40	385	196.1	165	73.9
.....	6,044.52	16 to 20	38	3.3	140	60.0	5,279.47	360	182.2	165	73.9
.....	4,564.57	16 to 22	38	3.3	140	60.0	4,009.97	360	182.2	165	73.9
.....	4,387.55	16 to 20	40	4.4	140	60.0	4,090.39	360	182.2	165	73.9
.....	4,184.45	16 to 18	40	4.4	145	62.8	3,853.36	400	204.5	170	76.7
Total.....	68,126.30	.....	.....	.....	.....	.....	58,415.91	.....	.....	.....	.....
Average per day.....	5,677.2	18.5 to 25.67	42.3	5.7	142	61.1	4,867.99	392	200	170	76.7

RECORD 2.

1916.											
Dec. 27.....	5,090.02	18.6	60	15.6	145	62.8	4,326.28	375	190.6	180	82.2
28.....	5,056.20	15.7	54	12.2	150	65.6	4,254.15	390	196.0	176	80.0
29.....	5,350.43	15.7	54	12.2	143	61.7	4,510.09	394	201.1	176	80.0
30.....	4,245.16	16.6	46	7.8	142	61.1	3,635.31	375	190.6	178	81.1
31.....	4,272.86	20.1	50	10.0	140	60.0	3,688.70	364	184.5	178	81.1
1917.											
Jan. 1.....	4,579.99	19.5	56	13.3	145	62.8	4,140.74	362.5	183.5	167	75.0
2.....	5,030.85	20.4	54	12.2	140	60.0	4,421.36	360	182.2	178	81.1
Total.....	33,625.51	.....	.....	.....	.....	.....	28,976.63	.....	.....	.....	.....
Average daily.	4,803.64	18.1	53.4	11.9	143.5	62	4,139.52	374.4	190.2	173.3	78.5

The heat exchangers were constructed of 1,540 feet of 6-inch pipe jacketed with 12½-inch pipe, and therefore, neglecting the thickness of the 6-inch pipe, had a heating surface of 2,556.40 square feet and a radiating surface of 5,241.13 square feet. The following calculations apply:

Let θ_a be temperature difference between the two liquids at commencement.

Let θ_e be temperature difference between the two liquids at end.

Then the mean temperature difference, θ_m, between the two liquids can be expressed by the formula[a] $\theta_m = \dfrac{\theta_a - \theta_e}{\log_e \dfrac{\theta_a}{\theta_e}}$

Substituting, $\theta_m = \dfrac{250-127.7}{\log_e 1.95} = \dfrac{102.3}{0.6678} = 183.1°$ F.

The actual rate of heat transfer then can be computed from the formula,[b]

$$K = \frac{F_w S (t - t_1)}{H \theta_m}$$

[a] Grashof, Franz, Theoretische Maschinenlehre, Bd. 1.

[b] Hausbrand, E., Evaporating, condensing, and cooling apparatus, 1916.

Gravity of residuum=16.0° B. (specific gravity, 0.959),
Weight per barrel=336 pounds,
t=temperature of fluid at beginning,
t_1=temperature of fluid at end,
F_w=weight of residuum passing per hour=68,076,
Specific heat of residuum taken as 0.4,
H=heating surface, 2,556.40 square feet, and
θ_m=mean temperature difference=183.1°.

Then $K=\frac{68,076\times0.4(392-170)}{2,556.40\times183.1}=\frac{5,506,591.10}{468,076.84}=11.7$ B. t. u. per hour per square foot per degree mean temperature difference.

Or, where F_w=weight of oil and water passing per hour,
Gravity of oil=18° B.,
F_w=78,345.36 pounds of oil+23,437.05 pounds of water=101,782.41 pounds of fluid,
Weight per barrel=331.2 pounds,
S=specific heat of mixture=0.58,
H=heating surface, 2,556.40 square feet,
θ_m=mean temperature difference=183.1,

then $K_1=\frac{101,782.41\times0.58(142-42.3}{2,556.40\times183.1}=\frac{5,851,638.26}{468,076.84}=12.5$ B. t. u. per hour per square foot per degree of mean temperature difference.

For record 2:

For residuum $K=\frac{57,901.54\times0.4(201.1)}{2,556.40\times170.1}=10.7$ B. t. u.

For oil and water $K_1=\frac{81,745.68\times0.55(90.1)}{2,556.40\times170.1}=\frac{45,286.36(90.1)}{434,843.64}=9.4$ B. t. u.

In record 2 the difference between K and K_1 (1.3 B. t. u.) multiplied by 2,556.40 times 170.1 represents the difference between the apparent total available heats of the two fluids. This difference, then, is $1.3\times2,556.40\times170.1=565,946.73$. Dividing this value by the number of square feet, 5,241.13, in the outside surface of the 12½-inch pipe gives $\frac{565,946.73}{5,241.13}=107.9$ B. t. u., the total loss in heat by radiation per square foot per hour from the crude oil and water passing through the jacket.

Although the rate of heat transfer accomplished in this heat exchanger is high, the writer's opinion is that an apparatus permitting readier accessibility for repairs, though possibly developing a lower rate of transfer, would be more practical.

FUEL CONSUMPTION.

Table 15 and figure 11 were prepared by the company's chemist from actual records of fuel consumption for the plant when topping oils of various gravities and water contents. They are the only available records of fuel consumption, as the company at present is using considerable gas for fuel, and is making no effort to meter the quantity consumed.

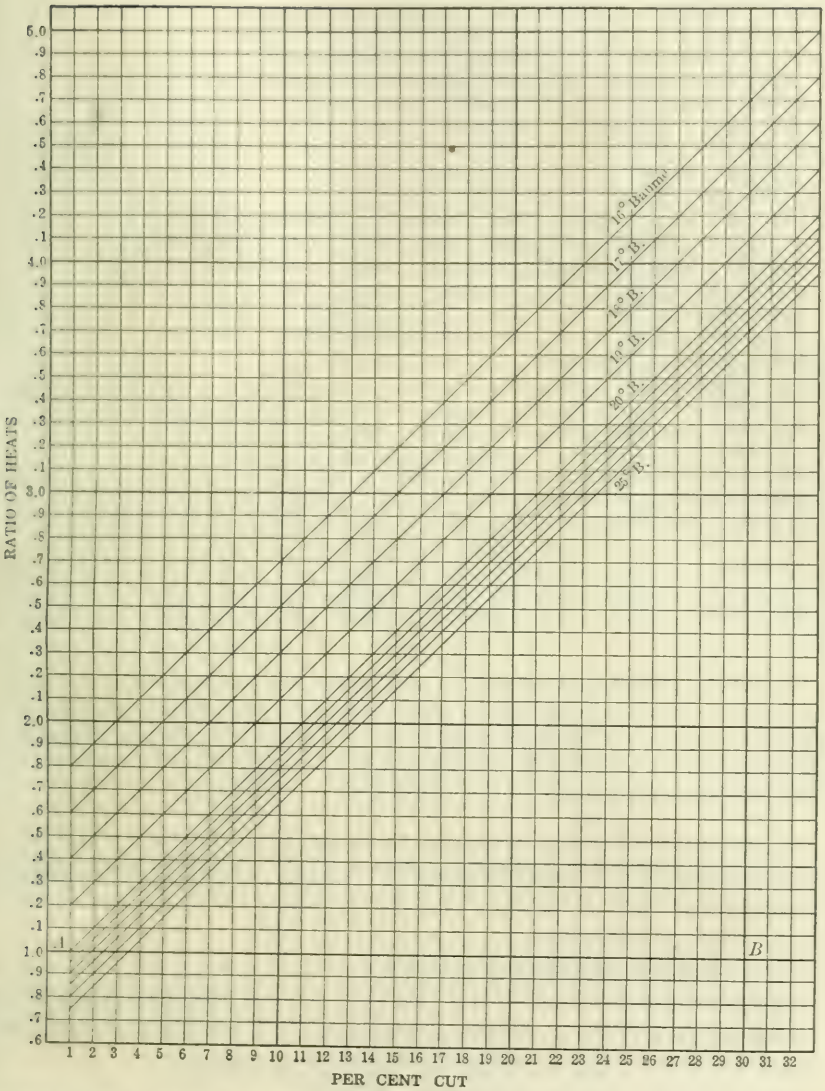


FIGURE 11.—Chart for use in computing fuel consumption at I. W. Fuqua's topping plant. Example showing method of using chart: Find the heat required to make a 15 per cent cut of 20° B. dry oil. On the line *A B* find the 15 per cent line and follow it to the point at which it is intersected by the 20° line, thence to the left and find the factor 2.4 in the line "ratio of heats." Multiply 2.4 by 34,750 (shown in Table 15 to be number of B. t. u. required for 1 per cent cut of 1 barrel of oil)=83,400 B. t. u. per barrel.

TABLE 15.—*Fuel required to top oils of various water contents, I. W. Fuqua plant.*

Per cent cut.	Factor.	B. t. u. per barrel of crude.	Percentage of water.									
			1 per cent.	2 per cent.	3 per cent.	4 per cent.	5 per cent.	6 per cent.	7 per cent.	8 per cent.	9 per cent.	10 per cent.
1	1.0	34,750	1.1	1.21	1.30	1.40	1.51	1.61	1.71	1.81	1.91	2.02
2	1.1	38,200	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.12
3	1.2	41,650	1.29	1.38	1.47	1.56	1.65	1.74	1.83	1.92	2.01	2.15
4	1.3	45,200	1.39	1.48	1.57	1.66	1.75	1.84	1.93	2.02	2.11	2.19
5	1.4	48,650	1.49	1.58	1.67	1.76	1.85	1.94	2.02	2.11	2.19	2.28
6	1.5	52,128	1.59	1.67	1.76	1.85	1.94	2.02	2.11	2.19	2.28	2.37
7	1.6	55,500	1.68	1.77	1.86	1.95	2.03	2.12	2.20	2.29	2.37	2.46
8	1.7	59,078	1.78	1.87	1.96	2.04	2.13	2.21	2.30	2.37	2.46	2.55
9	1.8	62,600	1.88	1.96	2.04	2.14	2.22	2.31	2.39	2.48	2.56	2.64
10	1.9	66,000	1.98	2.06	2.14	2.22	2.30	2.38	2.46	2.54	2.62	2.70
11	2.0	69,400	2.08	2.16	2.24	2.32	2.40	2.48	2.56	2.64	2.72	2.80
12	2.1	73,000	2.18	2.26	2.34	2.42	2.50	2.58	2.66	2.74	2.82	2.90
13	2.2	76,400	2.28	2.36	2.44	2.52	2.60	2.67	2.75	2.83	2.91	2.98
14	2.3	80,000	2.38	2.46	2.54	2.62	2.70	2.78	2.85	2.93	3.01	3.09
15	2.4	83,400	2.48	2.56	2.64	2.73	2.81	2.89	2.97	3.05	3.13	3.21
16	2.5	86,900	2.58	2.66	2.74	2.81	2.89	2.97	3.05	3.13	3.21	3.29
17	2.6	90,200	2.68	2.76	2.83	2.91	2.99	3.07	3.15	3.23	3.31	3.39
18	2.7	93,900	2.78	2.86	2.94	3.02	3.10	3.18	3.25	3.33	3.41	3.49
19	2.8	97,200	2.88	2.96	3.04	3.12	3.20	3.28	3.35	3.43	3.50	3.58
20	2.9	100,800	2.98	3.06	3.14	3.22	3.29	3.37	3.45	3.53	3.61	3.69
21	3.0	104,200	3.08	3.16	3.23	3.31	3.39	3.46	3.54	3.62	3.70	3.78
22	3.1	107,800	3.18	3.26	3.33	3.41	3.49	3.57	3.65	3.73	3.81	3.89
23	3.2	111,200	3.27	3.34	3.41	3.48	3.55	3.62	3.69	3.76	3.85	3.91
24	3.3	114,800	3.37	3.44	3.51	3.58	3.65	3.72	3.79	3.86	3.93	3.99
25	3.4	118,100	3.47	3.53	3.60	3.67	3.74	3.81	3.87	3.94	4.01	4.08
26	3.5	121,800	3.57	3.63	3.70	3.76	3.83	3.89	3.96	4.03	4.10	4.17
27	3.6	125,000	3.67	3.73	3.79	3.86	3.92	3.98	4.05	4.12	4.19	4.26
28	3.7	128,800	3.76	3.82	3.89	3.95	4.01	4.08	4.14	4.21	4.28	4.35
29	3.8	132,100	3.86	3.93	3.99	4.05	4.12	4.18	4.25	4.31	4.38	4.44
30	3.9	135,400	3.96	4.03	4.10	4.16	4.22	4.29	4.35	4.42	4.48	4.55

EXAMPLE.—Suppose the oil in the example given beneath figure 11 contains 5 per cent water. Find heat required to make same cut. After finding the factor 2.4 in figure 11, find 2.4 in column headed "Factor." Follow this line to right to column headed 5 per cent and find the new factor 2.81. Multiply 34,750 (B. t. u. per barrel crude) by this factor=97,647.50 B. t. u. per barrel.

If, for example, it is required to make a 15 per cent cut from a dry oil of 18° B. (specific gravity, 0.946), Table 15 and figure 11 show that 97,300 B. t. u. would be required for each barrel of oil going through the plant.

Theoretically, the fuel consumed to remove a 15 per cent cut of vapors from one barrel of 18° B. dry oil, assuming that no losses occurred in any part of the apparatus, and considering the heat recovery in the heat exchangers, would be as follows:

Assume the oil to have this approximate analysis:

Assumed proximate analysis of oil.

[Oil sample. Gravity, 19.2° B. (0.938).]

	Specific gravity of fraction.	Distillate.		Specific gravity of fraction.	Residue.	
		By volume.	By weight.		By volume.	By weight.
		Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
Tops below 250° F. (121.1° C.)	0.739	5	3.93	0.950	95	96.07
Tops 250° to 350° F. (121.1° to 176.6° C.)	.827	10	8.83	.963	85	87.24

Steam used in refining 5 per cent= 0.005 barrel.
Specific heat of oil = 0.43 approximately.
Latent heat of oil =125 approximately.
Latent heat of water =970 approximately.

			B. t. u.
Heat 1 pound of oil 165° to 250° F. (73.9° to 121.1° C.)	1	(250−165)× 0.45=	38.25
Evaporate 0.039 pound of tops	0.039	×125 =	4.87
Superheat 0.039 pound of vapors 250° to 350° F. (121.1° to 176.6° C.)	.039	(350−250)× 0.5 =	1.95
Heat 0.96 pound of oil 250° to 350° F. (121.1° to 176.6° C.)	.96	(350−250)× 0.45=	43.20
Evaporate 0.088 pound of tops	.088	×125 =	11.00
Heat 0.005 pound of boiler water to 212° F. (100° C.)	.005	(212− 60)× 1.00=	0.76
Evaporate 0.005 pound of boiler water at 212° F. (100° C.)	.005	×970 =	4.85
Superheat 0.005 pound of steam 212° to 310° F. (100° to 154.5° C.)	.005	(310−212)× 0.50=	0.25
Heat consumed per pound of oil topped at 100 per cent efficiency			105.13

Or, as a barrel of 18° B. oil weighs 331.2 pounds, theoretically the total heat required to top off 15 per cent of one barrel of this oil would be: 105.13×331.2=34,819 B. t. u., or 0.58 per cent of the crude run.

Table 15, however, shows that the plant uses 97,300 British thermal units, or 1.6 per cent of the crude run. Therefore the over-all efficiency of the plant would appear to be $\frac{0.58}{1.6}$=36 per cent.

STEAM CONSUMPTION.

Under normal operation the plant required about 150 boiler horsepower of steam per day.

WATER CONSUMPTION.

The cooling water system installed seems to be very efficient.

The highest atmospheric temperature recorded in 1914 was 114° F. (45.6° C.), at 2 p.m., and the water was being pumped to the towers at 156° F. (68.9° C.). After leaving the towers and passing through a 4-inch pipe 200 feet long buried 1 foot underground, the water reached the condensers at 62° F. (16.7° C.). At that time the company was dehydrating from the crude run about 800 barrels

daily, which passed into the cooling water to replace water lost by evaporation. The company calculated that there was continuously about 2,500 barrels of water in the plant, which, at the rate of pumping over the towers, had to pass through the towers more than four times in 24 hours. That is, the four towers cooled between 10,000 and 12,000 barrels of water in 24 hours. The loss from evaporation therefore would be approximately represented by the water dehydrated from the oil—6 to 7 per cent.

During December, 1916, approximately 5,000 barrels of water was pumped over the towers in 24 hours.

FIRE HAZARD.

There have been no fires in this plant since it began work.

REPAIRS.

Largely because of the nature of the oil handled, frequent overhauling and repair of the apparatus is necessary.

The heat exchangers at the time of the writer's inspection of the plant had not been cleaned for two years and the space between the 6-inch and the 12½-inch pipes was badly fouled with sand and scale. To properly clean the pipes it was necessary to unscrew each joint and to scrape, a costly operation.

The company therefore adopted the expedient of forcing all the incoming oil through one heat exchanger under an increased pump pressure in an attempt to remove the sediment when the same operation was repeated on the other exchanger. When this was first attempted, only 4,000 barrels could be put through in 24 hours with a 200-pound pump pressure, but after the plant had been running one month 7,000 barrels could be forced through with a 160-pound pressure.

As a consequence of this method the first water trap required cleaning every fifth day, the second one every two weeks, and the last one every six weeks. The oil warmers were cleaned every 30 days. The lower heater coils at first gave considerable trouble, being replaced as often as every 30 days until the combustion chambers were enlarged to their present size. Since then the heaters have run four to six months without a shutdown for cleaning or repairs. Incrusting, due to the impurities contained in the water accompanying the oil, is responsible for part of the trouble, though the fact that the oil does not have a continuous upward flow through the heaters, thus forming gas jackets in the coils and causing local superheating and burning of the tubes, is undoubtably a contributing factor.

No other repairs of importance have been necessary and the plant has been running continuously for four years handling oils of various grades and different water content.

COST OF PLANT.

The approximate cost of the entire plant was $150,000, representing a cost of about $7 per barrel of capacity, which compares favorably with similar plants.

CHANGES AND IMPROVEMENTS POSSIBLE.

Though this plant is successful, it is believed that several changes are possible that would make for greater economy and uniformity of products. The use of long headers should be avoided. The three batteries of heaters might be operated in series and fractionation accomplished directly during heating. This arrangement might possibly reduce the capacity of the plant, but would eliminate the first cost and the cost of operating the rerun plant. It would also reduce the length of the headers feeding the heaters, as each battery would be independent of the others.

The heaters might be rendered more efficient by a rearrangement of the coils and heating surfaces to permit more even heating, and the oil should flow continuously upward through the coils, leaving at the top. The pipes as arranged in the heaters rest practically upon each other so that complete circulation of the hot gases around them is probably not attained.

The fractions obtained by fractional heating could be again fractionated probably to desired specifications by a system of dephlegmators placed in the vapor lines from the separators, abolishing the inverted U pipes at present used.

E. I. DYER PLANT, AVILA, CAL.

The E. I. Dyer plant at Avila, Cal., was designed by E. I. Dyer and his associates to clean and top a very wet emulsified oil from the Santa Maria fields.

The water carried in this oil contains many scale-forming elements, so that handling it in the ordinary still directly fired is practically impossible because of coking and continual priming.

After considerable experimenting, the principle of multiple evaporation was adopted, steam being used as a heat medium. The low temperatures attained in the stills eliminated the coking and other difficulties encountered when the oil was subjected to a direct furnace heat.

GENERAL DESCRIPTION.

The plant in general consists of 12 cylindrical steam stills arranged in two rows of six each, one above the other. The upper rows are low-pressure and the lower rows high-pressure stills. In normal operation the plant runs by double effect, the stills being divided into six groups each of one high and one low pressure still.

Two heat exchangers and one condenser of similar design are provided with each group of two stills, and a boiler plant of five 300-horsepower Stirling boilers completes the installation.

Subsequent to the original installation, three large spray-cooled condensing coils were constructed, replacing the old condensers. Plate XXIV, B (p. 58) shows a general view of the plant.

DETAILED DESCRIPTION OF APPARATUS.

STILLS.

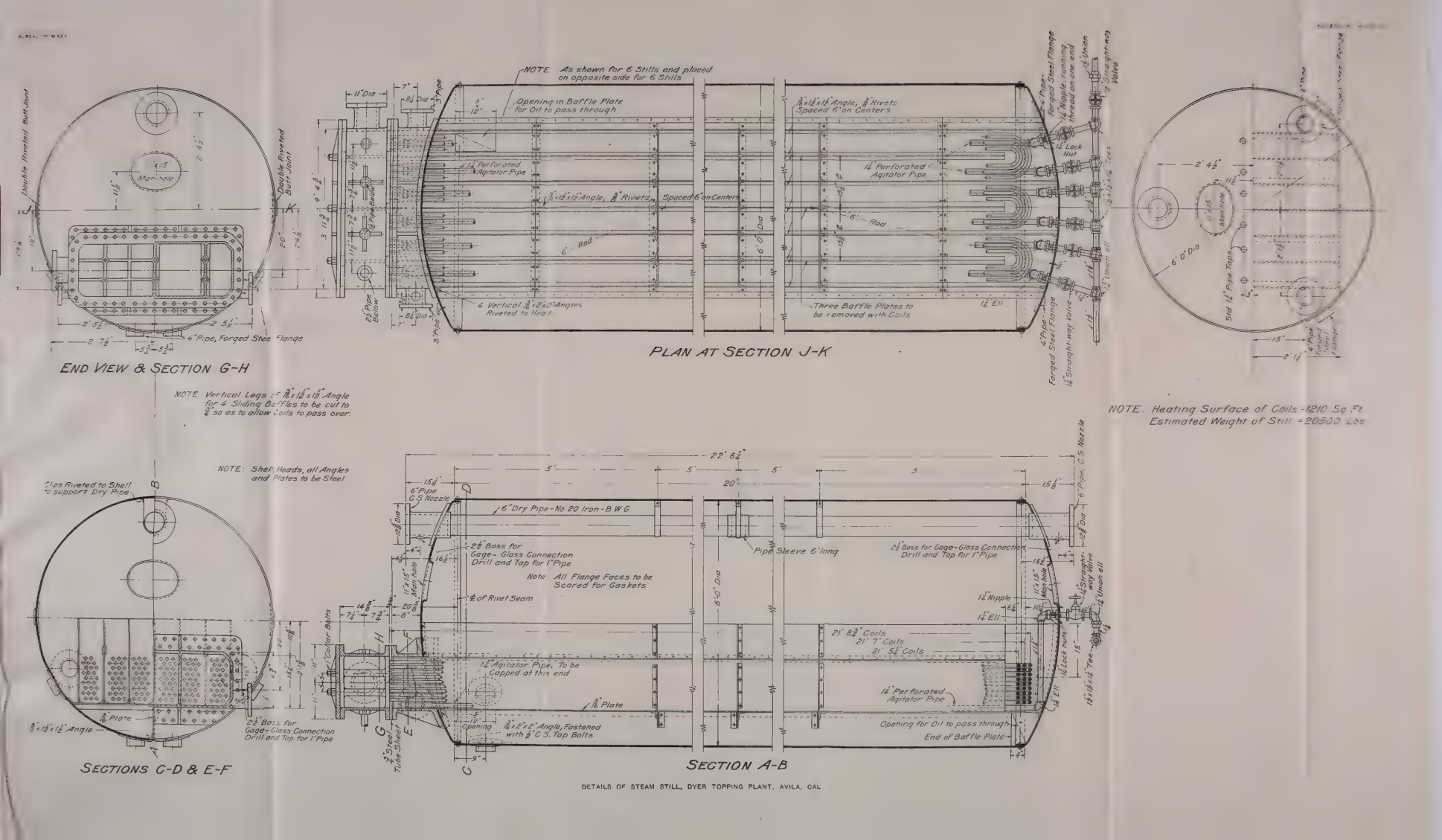
The stills are cylindrical steel shells of $\frac{3}{8}$-inch plate, 6 feet in diameter and 20 feet long, fitted with convex heads, to one of which a large steam chest is riveted. The steam chest is divided into four compartments, and on the side nearest the still a $\frac{3}{4}$-inch steel tube sheet is bolted. Within the still a horizontal $\frac{3}{16}$-inch plate is supported flush with the lower level of the steam chest and running the full length of the still. Above this plate four vertical baffles riveted by angles to the shell form three equal compartments extending also the full length of the still and the width of the steam chest.

One set of 27 $1\frac{1}{4}$-inch return tubes is fitted in each compartment, the ends of the tubes being rolled into the tube sheet in the steam chest. Each compartment is divided in half by baffles supported by these coils and removable with them. As indicated in Plate XXV the steam entering the steam chest passes back and forth through the coils three times before leaving on the opposite side of the chest, and oil admitted into the still through the 3-inch opening just back of the steam chest travels an equal number of times back and forth in the still, being guided by the vertical baffles in a path opposite to the steam current. A 6-inch dry pipe is suspended within the still for the collection of the vapors, and a manhole, 11 by 15 inches, is provided at each end of the still.

Drains are provided from each compartment of the steam chest so that condensate is drawn from the coils as fast as formed. Automatic drip pumps return this water to the boilers at an average temperature of 280° F. (137° C.). A $1\frac{1}{4}$-inch perforated steam pipe extends the full length of each compartment in the stills for the purpose of introducing steam for agitation. The entire still is heavily insulated with an asbestos covering to prevent radiation losses. Plate XXVI, *A*, shows the foward end of the stills and the interconnecting piping, and Plate XXIV, *C* (p. 58), shows a view of the Cottrell dehydrating plant used in conjunction with the topper.

HEAT EXCHANGERS.

The heat exchangers are rectangular still boxes, 3 by 6 by 21 feet, fitted on one end with a cast-iron manifold containing four compartments. A $\frac{1}{2}$-inch steel tube sheet is bolted to the manifold, and 66 1-inch pipes are threaded into each compartment. These pipes extend the full length of the exchanger, and are joined at the opposite ends by short nipples and ells. Within the exchanger two vertical baffles are placed, which force the fluid around the pipes to travel in a path opposite to the flow of the fluid within them in its course



DETAILS OF STEAM STILL, DYER TOPPING PLANT, AVILA, CAL

through the apparatus. The fluid within the tube makes four passes in its course through the apparatus.

The entire set of pipes and baffles can be removed from the shell of the exchanger for cleaning or repairs, as will be seen from Plates XXVI, *B*, XXVII, and XXVIII. Plate XXIX (p. 78) shows the detailed construction of this exchanger.

Data on apparatus shown in Plate XXIX.

[External heating surface of piping, 1,880 square feet; of fittings, 32 feet; of tube sheets, 8 feet; total heating surface, 1,900 square feet.]

BILL OF MATERIAL FOR ONE-HEAT EXCHANGES.

No.	Part.	Length.		Number required.
		Ft.	*In.*	
1	1-inch standard pipe	20	$4\frac{1}{4}$	24
2	.....do	20	$3\frac{3}{4}$	20
3	.....do	20	$2\frac{1}{4}$	24
4	.....do	20	$1\frac{3}{4}$	20
5	.....do	20	$\frac{3}{4}$	24
6	.....do	19	$11\frac{3}{4}$	20
7	.....do	19	$10\frac{1}{4}$	24
8	.....do	19	$9\frac{3}{4}$	20
9	.....do	19	$8\frac{3}{4}$	24
10	.....do	19	$7\frac{3}{4}$	20
11	.....do	19	$6\frac{3}{4}$	24
12	.....do	19	$5\frac{3}{4}$	20
13	1-inch union ell			132
14	1-inch ell			132
15	1-inch nipple		$3\frac{3}{4}$	22
16	.....do		$7\frac{3}{4}$	22
17	.....do		$11\frac{3}{4}$	22
18	.....do		$15\frac{3}{4}$	22
19	.....do		$19\frac{3}{4}$	22
20	.....do		$23\frac{3}{4}$	22
21	Cast-iron manifolds, 1 right-hand and 1 left-hand			2
22	Cast-iron covers, 1 right-hand and 1 left-hand			2
23	Tube sheets of tank steel $\frac{1}{2}$-inch thick, 1 right-hand and 1 left-hand			2
24	Angle iron, $2\frac{1}{2}$ by $2\frac{1}{2}$ by $\frac{3}{16}$ inch	2	$4\frac{7}{8}$	2
25	Baffle plate of No. 10 tank steel			2
26	Supporting plate of No. 10 tank steel			6
27	.....do			6
28	Stud, $\frac{3}{4}$-inch	1	$7\frac{1}{4}$	16
29	.....do		4	4
30	Special 4-inch ell, cast-iron, with boss and pipe tap			4
31	Special blind cast-iron flange, 10-inch, with boss and pipe tap			2
32	Stud, $\frac{3}{4}$-inch		3	16
33	Standard 1-inch pipe, drilled as shown	19	6	4
34	Standard 1-inch malleable iron offset			4
35	.....do			4
36	Standard 1-inch flange union, extra heavy			4
37	Pressed-steel 2-inch boiler flange			4
38	Cast-iron 1-inch elbow, extra heavy			2
39	Cast-iron tee, 1 by $1\frac{1}{2}$ by 1 inch, extra heavy			2
40	Cast-iron tee, $1\frac{1}{2}$ by $1\frac{1}{2}$ by 2 inches, extra heavy			1
41	Nipple, 1-inch		6	4
42	Nipple, 1-inch, closed			4
	Tap bolt, $\frac{3}{4}$-inch		$2\frac{3}{4}$	10
	Standard bolt, $\frac{3}{4}$-inch		3	123
	Standard nut, $\frac{3}{4}$-inch			46

CONDENSERS.

The first condensers are described here as they were in use when the data given in this description were compiled. They are rectangular steel boxes 2 feet 6 inches by 4 feet 3 inches by 20 feet 9 inches, with a manifold and tube sheet flanged to one end and a cover plate to the other. Into this tube sheet four rows each of twenty-four 2½-inch boiler tubes are expanded and connected at the opposite end to form a continuous path for the vapors from the top compartment of the manifold to the exit on the bottom. The manifold is divided by three horizontal partitions into four equal compartments. Within the condenser three horizontal baffles force the cooling water surrounding the tubes to flow opposite to the path of the vapors in passing from the 3-inch flanged connection on the bottom of the box near the manifold to the 3-inch outlet directly above. (See Pl. XXX, p. 80.)

SPRINKLER TYPE OF CONDENSER.

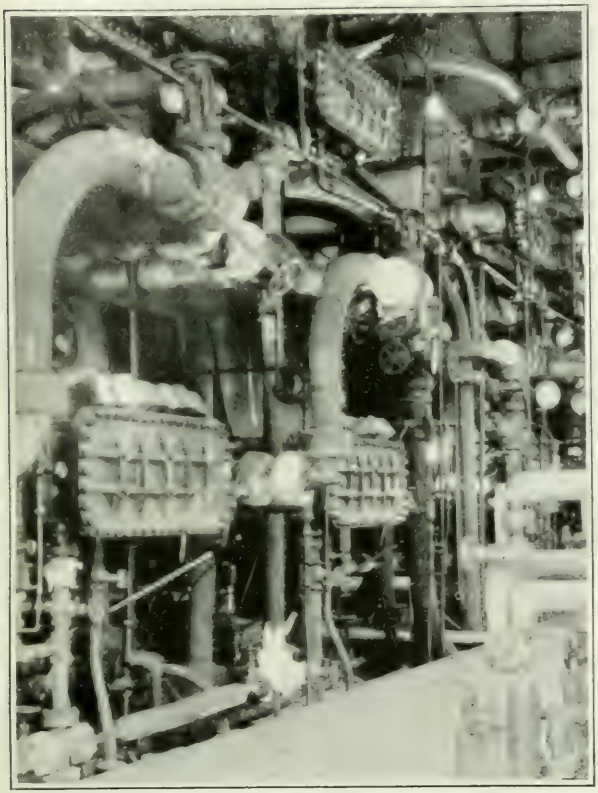
Each condenser consists of thirty-six 36-foot lengths of 4-inch cast-iron pipe arranged in six horizontal rows of 6 pipes each with sixteen 36-foot lengths of 3-inch cast-iron pipe similarly arranged below. The pipes are connected end to end by flanged elbows and nipples to form a continuous coil which is arranged to drain to the outlet at the bottom. The entire coil is supported by a series of cast-iron columns fitted with brackets and cross connections to insure rigidity. The cooling water is sprayed over the coils and returns by gravity to the reservoir supplying the cooling-water pumps. Plate XXXI (p. 82) shows the arrangement of these coils and supports. Plate XXXII (p. 84) is a general plan showing the plant arrangement, and Plate XXXIII (p. 86) illustrates the piping connecting the stills.

OPERATION.

In connection with the running of plant, it must be noted that the oil handled has steadily shown a larger water content since the time of construction. With this increase of water the plant capacity correspondingly decreased until recently it was found necessary to install an electrical dehydrating plant, which treats a part of the oil and reduces the water content of the entire amount to a percentage that permits the refinery to handle the daily receipt without accumulating stocks.

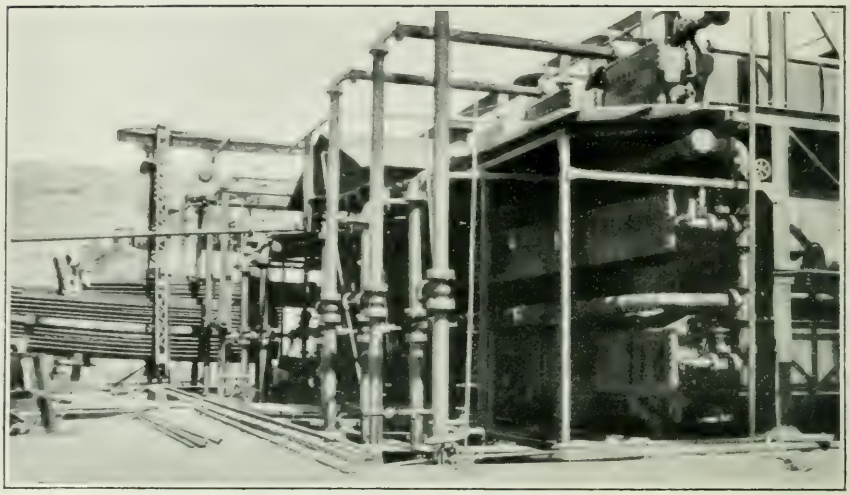
The crude-oil flow chart shown in figure 12 illustrates the by-pass arrangement that permits a portion of the entering oil to pass through the electrical dehydrator and after treatment to mix with the rest flowing to the heaters.

Crude oil enters the plant at approximately atmospheric temperature through a header connecting the six sets of heat exchangers, and

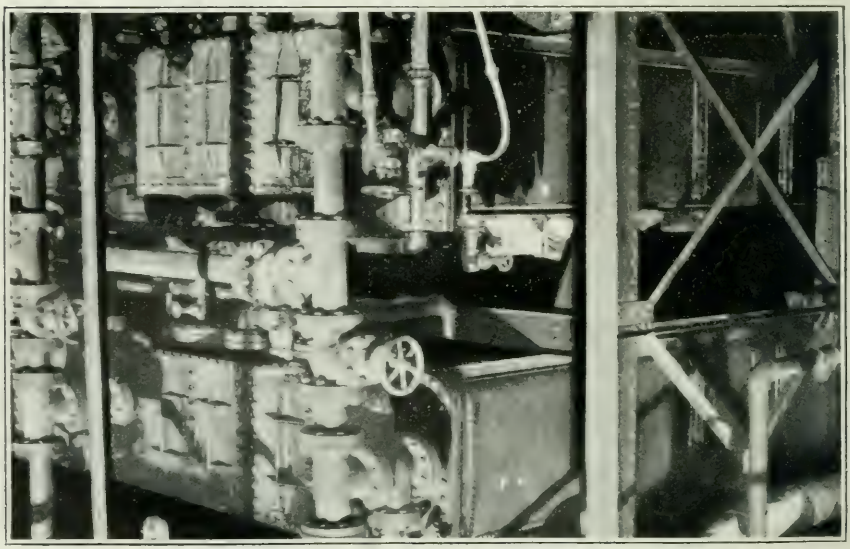


A. FORWARD END OF STILLS SHOWING INTERCONNECTING PIPING. DYER TOPPING PLANT.

B. HEAT EXCHANGER TUBES BEING REMOVED FOR REPAIRS. DYER TOPPING PLANT.



A. GENERAL VIEW OF HEAT EXCHANGERS AND BOX CONDENSERS. DYER PLANT.



B. FRONT VIEW OF HEAT EXCHANGERS, DYER PLANT.

passes in series through the tubes of the two in each set countercurrent to the outgoing residuum. Thence a part of the warm oil is by-passed through the electrical dehydrator and returns to the main oil line feeding the stills. This oil line also connects the six sets of stills in parallel. The oil first enters the upper or low-pressure still of each set and passes back and forth through the still, being heated by the hot vapors within the tubes from the high-pressure still. Vapors

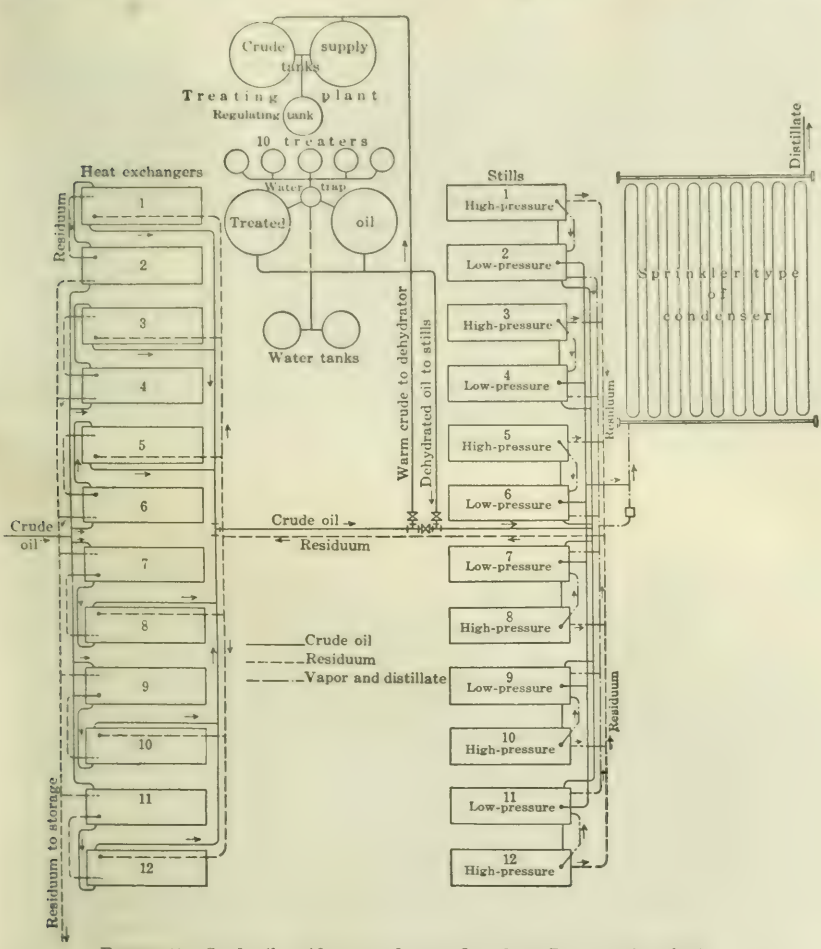


FIGURE 12.—Crude oil, residuum, and vapor flow sheet, Dyer topping plant.

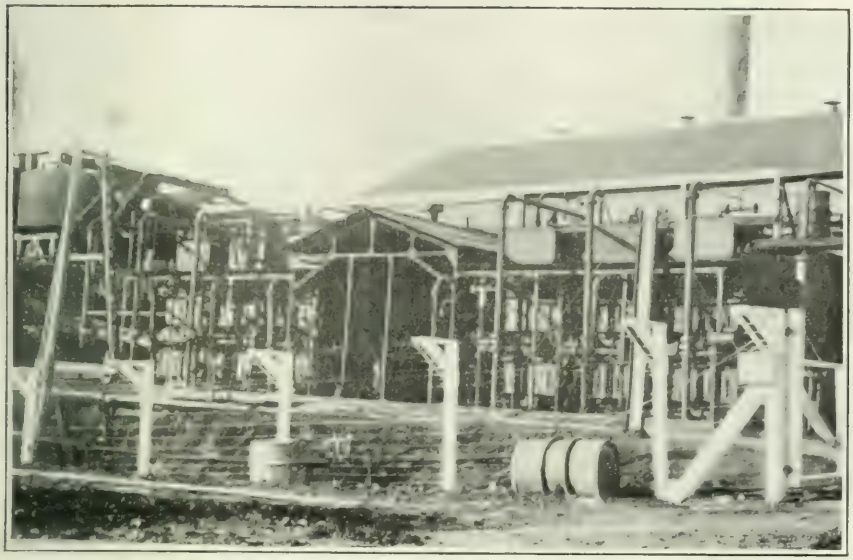
evolved in the low-pressure still are withdrawn through the dry pipe and pass directly to the condensers. The liquid residue in the upper still is pumped to the lower still and passes as before back and forth over the tubes containing live steam at about 150 pounds pressure. The lower still works under a vapor pressure of about 50 pounds per square inch. The vapors under this pressure enter the coils of the upper stills and as condensate flow to the condenser to be cooled.

In this way all the latent heat of both the oil and the water vapors is transferred to the fluid in the upper still.

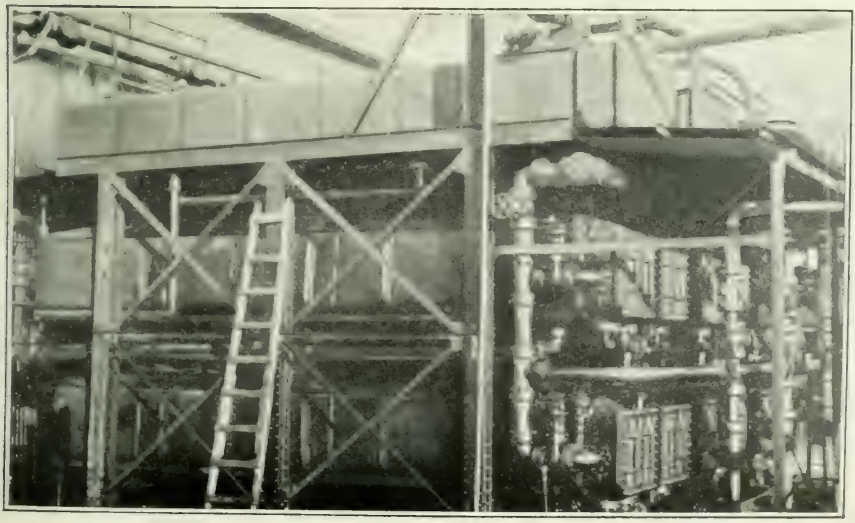
The residual oil from the lower still flows through the heat exchangers in series, passing around the tubes countercurrent to the incoming oil and thence to storage.

While the plant is running the evaporation of the water content in the oil leaves a deposit of salt crystals in the stills which is removed from them periodically by circulating hot water that carries the salt away in solution. Experience had with this oil when treated in fire-heated stills showed that this deposit induced coking and resulted in a hard incrustation over the still bottom that necessitated frequent shut-downs for cleaning and repairs.

The following tabulations constitute a three months' record of plant operation for October, November, and December, 1912, and form the basis for the theoretical computations following.



A. GENERAL VIEW OF EXCHANGERS AND CONDENSERS. DYER PLANT.



B. RIGHT-HAND VIEW OF CONDENSERS AND EXCHANGERS. DYER PLANT.

TABLE 16.—*Three months' record of crude run and products made in 1912 at Avila plant.*

Month.	Total crude run.	Average crude run per day.	Corrected gravity of crude.		Average water distilled per day from crude.	Average residuum produced per day.	Gravity of residuum.		Average distillate produced per day.	Gravity of distillate.		Average daily refining loss.	Average daily fuel consumed.[a]	Gravity of fuel consumed.		Average pressure in high-pressure stills.
			°B.	Specific gravity.			°B.	Specific gravity.		°B.	Specific gravity.			°B.	Specific gravity.	
	Barrels.	*Barrels.*			*Barrels.*	*Barrels.*			*Barrels.*			*Barrels.*	*Barrels.*			*Pounds.*
October	242,613.51	7,826.24	18.9	0.940	1,518.8	4,951.77	16.5	0.956	1,104.9	53.4	0.765	86.9	160.76	16.5	0.956	35.5
November	233,312.36	7,777.07	19.2	.938	1,661.1	4,788.53	16.7	.955	1,116.14	54.6	.760	53.3	158.02	16.7	.955	35.7
December	210,939.53	6,804.50	18.7	.941	1,483.9	4,133.31	16.2	.958	1,012.98	54.4	.761	20.8	153.5	16.2	.958	34.8
Total	686,865.40	22,407.81	.....	.....	4,663.8	13,876.61	.....	.....	3,234.02	.....	.....	161.0	472.28	.....	.....	106.0
Average for period	228,955.13	7,469.27	19.0	.939	1,554.6	4,625.53	16.5	.956	1,078.00	54.1	.762	53.6	157.43	16.5	.956	35.3

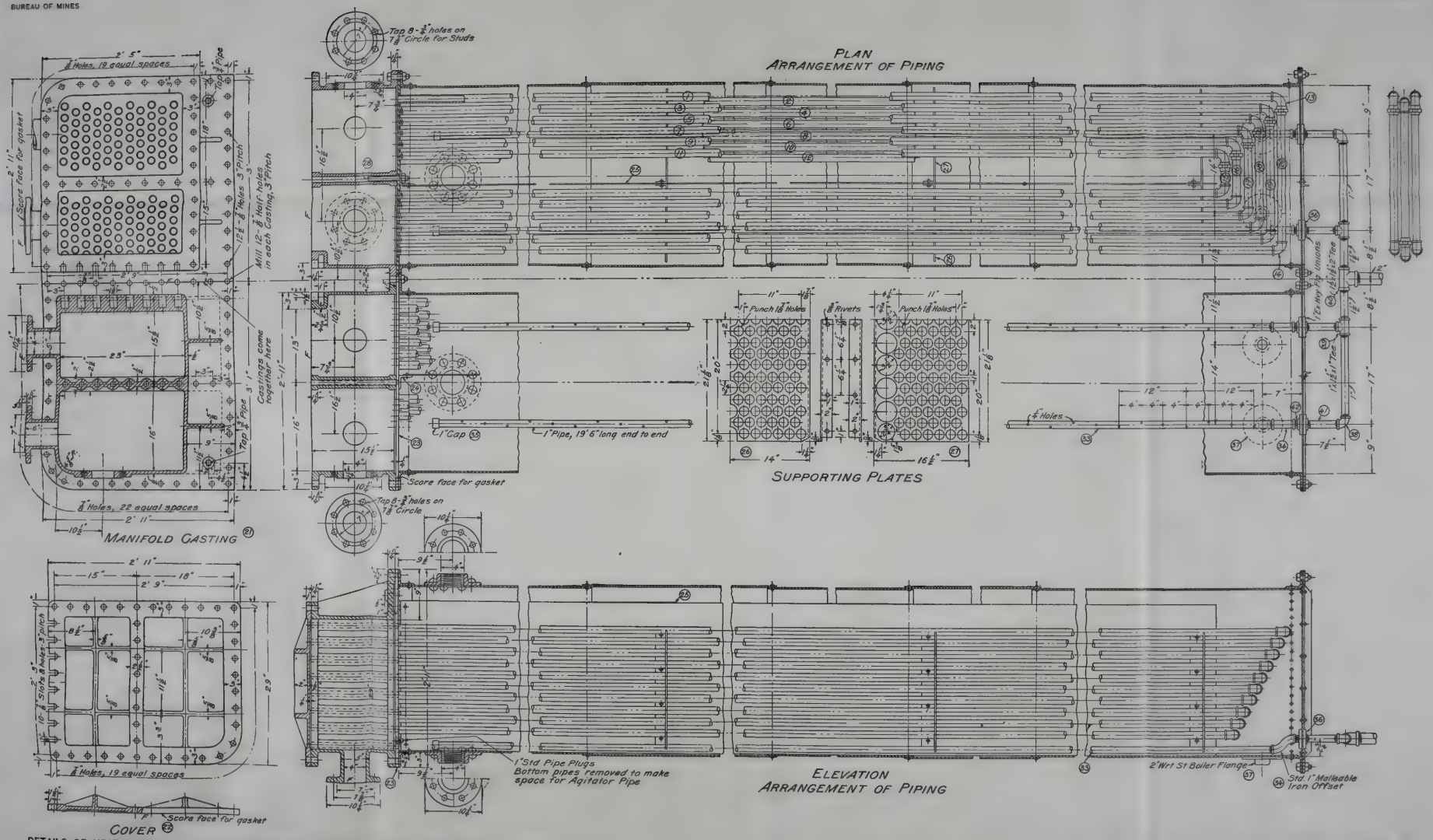
TABLE 17.—*Three month's record of heat exchangers, Avila plant, 1912.*

Month.	Oil and water passing per hour.	Per cent of water.	Specific heat of mixture.	Gravity per barrel of net oil.		Weight per barrel.	Temperature of oil.			
							Ingoing.		Outgoing.	
				° B.	Specific gravity.		° F.	° C.	° F.	° C.
	Barrels.					*Pounds.*				
October	326.1	19.3	0.55	18.9	0.940	330	75.6	24.2	127.3	52.9
November	324.0	21.4	.57	19.2	.938	329	70.1	21.1	127.6	53.1
December	283.5	21.7	.57	18.7	.941	331	65.8	18.7	125.9	52.1
Total	933.6	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average for period	311.2	20.8	.56	19.0	.939	330	70.5	21.3	126.9	52.7

[a] Fuel consumption shown includes operation of pipe-line pumping station in connection with the plant, power used in plant, and distillate transfer.

TABLE 17.—*Three months' record of heat exchangers, Avila plant, 1912*—Continued.

Month.	Residuum passing per hour.	Specific heat.	Gravity per barrel of residuum.		Weight per barrel.	Temperature of residuum.				Total external heating surface.	Mean temperature difference ($\theta\ m$).	Transfer rates.	
						Ingoing.		Outgoing.					
			° B.	Specific gravity.		° F.	° C.	° F.	° C.		° F.	K.	K_1.
	Barrels.				*Pounds.*					*Square feet.*			
October	206.44	0.4	16.5	0.956	335	261.9	127.7	152.8	67.1	.....	.....	.....	.....
November	199.52	.4	16.7	.955	335	265.8	129.8	145.5	63.1	.....	.....	.....	.....
December	172.22	.4	16.2	.958	336	260.7	127.1	137.6	58.6	.....	.....	.....	.....
Total	578.18	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average for period	192.73	.4	16.5	.956	335	262.8	128.2	145.3	62.9	22,800	93.88	1.6	1.4



DETAILS OF HEAT EXCHANGER, DYERS TOPPING PLANT, AVILA, CAL. EXTERNAL HEATING SURFACE OF PIPING, 1,860 SQUARE FEET; OF FITTINGS, 32, AND OF TUBE SHEETS, 8; TOTAL, 1,900 SQUARE FEET. FOR LIST OF MATERIALS SEE TABLE ON PAGE 74.

TABLE 18.—*Three months' record of distillate made and cooling water used in 1912, Avila plant.*

Month.	Distillate passing per hour.	Gravity of distillate.		Temperature of distillate leaving condenser.	Cooling water used per hour.	Temperature of water.	
						Entering condenser.	Leaving condenser.
	Barrels.	°*B.*	*Specific gravity.*	°*F.*	*Barrels.*	°*F.*	°*F.*
October	46.03	53.4	0.765	152.6	914.5	60.31	102.08
November	46.50	54.6	.760	138.3	932.3	58.29	87.24
December	42.20	54.4	.761	135.5	948.0	54.24	85.50
Average for period	44.91	54.1	.762	.....	931.6	.....	.....

EFFICIENCY OF HEAT EXCHANGE.

Based upon the following formulas and data the rate of heat transfer, K, in the exchangers was computed, and is shown in the table.

The mean temperature difference can be expressed by the formula:

$$\theta_m = \frac{\theta_a - \theta_e}{\log_e \frac{\theta_a}{\theta_e}}$$

Where θ_a=the temperature difference between the fluids at beginning.
θ_e=the temperature difference between the fluids at end.

The rate of transfer accomplished is low and should condemn this type of exchanger. Attention is called to the exchanger used with the conventional stills handling a similar quantity of oil. Seemingly with this type of apparatus considerably less heating surface would do the work accomplished by the twelve exchangers installed. The first cost would be much lower and less ground space would be required. Of course, viscosity enforces this transfer rate and undoubtedly a less viscous oil would show a greater transfer.

A record of distillate produced and of the cooling water used is given to show the volume of cooling water required with the old type of condensers. It is regretted that records covering the spray condensers are not available. The table shows a requirement of 20.7 barrels of cooling water to one barrel of distillate made. This is unusually large on account of the high-water content of the crude oil.

STEAM PRODUCTION.

The tabulation following presents a complete record of the boiler-plant operation for November, 1912. The combustion attained is creditable. The writer is indebted to Mr. E. I. Dyer for this record and also for the data forming the basis for the three months' plant record.

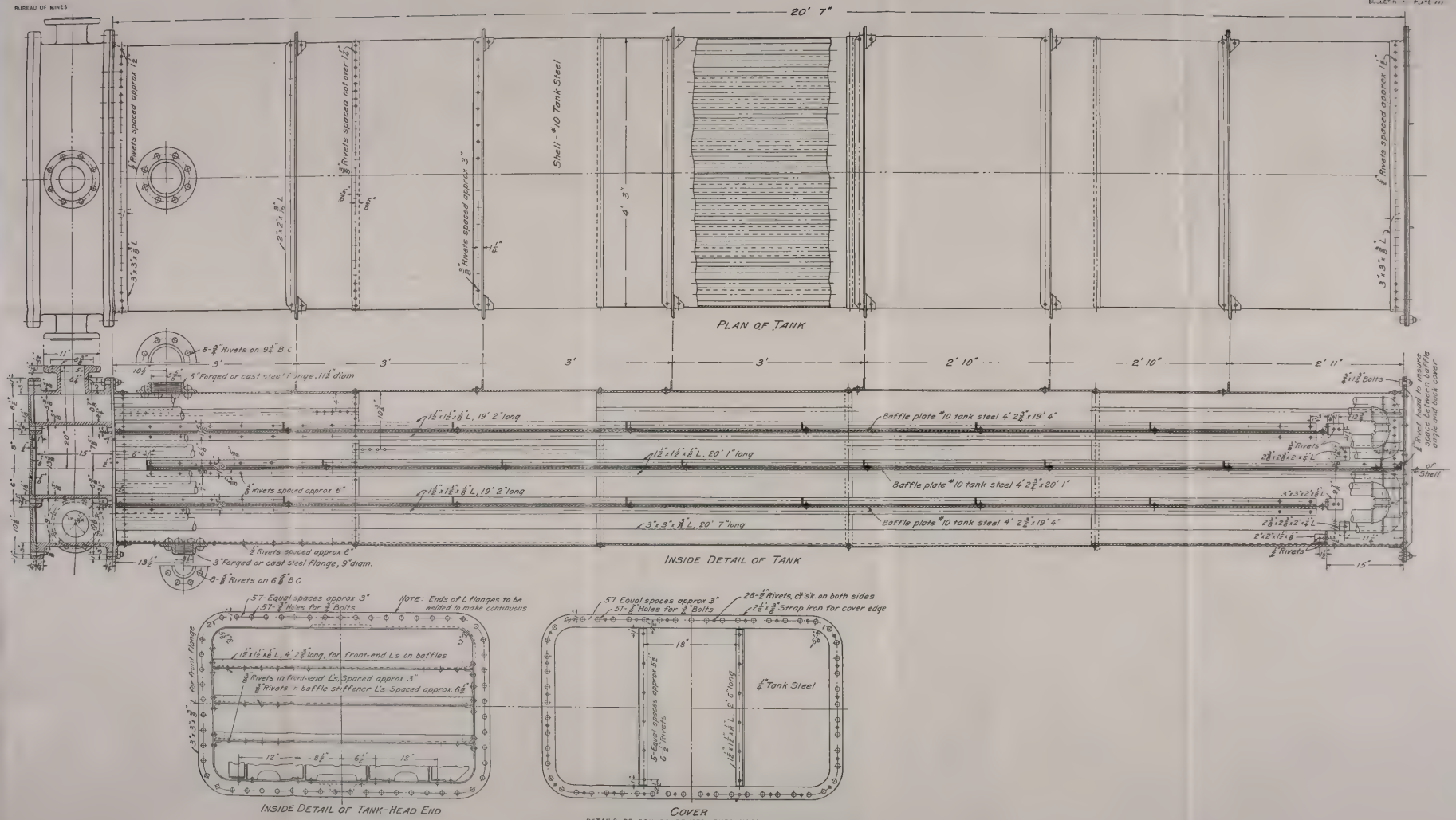
Record of operation for November, 1917, Avila plant.

Total feed water, thousands of pounds	22,907.09
Make-up water, thousands of pounds	9,078.98
Average temperature of feed water, °F	280.93
Average steam pressure, pounds	154.52
Average evaporation factor	.974
Total evaporation from and at 212° F., thousands of pounds	22,313.80
Average evaporation from and at 212° F. per pound fuel as fired, pounds	14.08
Average evaporation from and at 212° F. per pound of dry fuel, pounds	14.42
Average boiler efficiency, fuel as fired, per cent	73.19
Average flue gas temperature, °F	562.37
Average draft at base of stack, inch	.093
Average volume of CO_2, per cent	12.89
Average volume of CO, per cent	.008
Average volume of O, per cent	2.42
Average volume of N, per cent	84.68
Average volume of excess air, per cent	20.40
Total boiler horsepower developed, horsepower-hours	646,776.81

COST OF PLANT.

The estimated cost of the plant is $214,105, which represents a cost of $28.55 per barrel of daily capacity. This figure, however, includes the entire expenditures in connection with the refinery and can not therefore be compared with the itemized costs already presented for other plants.

Continuous operation of the refinery, since its completion, upon a badly emulsified oil has proven its design to be ideally adapted to its purpose. The plant efficiency is commendably high, comparing favorably with best boiler practice.



DETAILS OF BOX CONDENSER, DYER TOPPING PLANT, AVILA, CAL

The first cost is considerably higher than that of other plants described, owing in part to the unnecessary heat exchangers, as well as to the discarded condensers. However, the construction represents a pioneer effort along distinctly unique lines in the oil industry, and the designers merit considerable credit for the results attained.

BROWN-PICKERING PLANT.

GENERAL DESCRIPTION.

A Brown-Pickering plant was constructed in 1910, by A. B. Brown, on sec. 7, T. 3 S., R. 9 W., in the Fullerton field in California. It consists in general of three rectangular stills about 4 by 4 by 20 feet, two 40-horsepower California-type tubular boilers, used as prewarmers, two horizontal cylindrical vapor separators, and a series of condensing coils and boxes. In addition, a heat exchanger, consisting of eight runs of 12-inch pipe 40 feet long containing several small pipes, is provided.

DETAILED DESCRIPTION OF APPARATUS.

STILLS.

Each still consists of a steel box 4 by 20 feet by 4 feet high, provided with a removable flanged cover bolted to the box. Vertical baffles 2 feet high and about 3 feet 6 inches long are set across the still bottom every 8 inches. They extend to within 6 inches of the sides, alternating in position, so that the space at the end of the baffles is first adjacent to one side of the still, and then to the other. The still is set with a fall of 18 inches in its length, over a brick furnace containing a continuous coil of 19 2½-inch pipes 21 feet long. This coil is placed close to the still bottom, permitting a combustion chamber about 2 by 4 by 24 feet in size.

Underground flues convey the combustion gases to the prewarmers. (See fig. 13 and Pl. XXXIV, *A*, p. 88.)

PREWARMERS.

The prewarmer is an ordinary 40-horsepower California tubular type of drilling boiler, bricked up so that the flue gases make a first pass beneath the boiler, then return through the tubes and out the stack. There are 40 3-inch tubes 12 feet long, and the heating surface is approximately 479 square feet. Plate XXXIV, *B*, p. 88, shows the stills and prewarmers.

CONDENSERS.

Six wooden condenser boxes are provided, each containing 13 3-inch wrought-iron pipes 20 feet long connected by return bends to

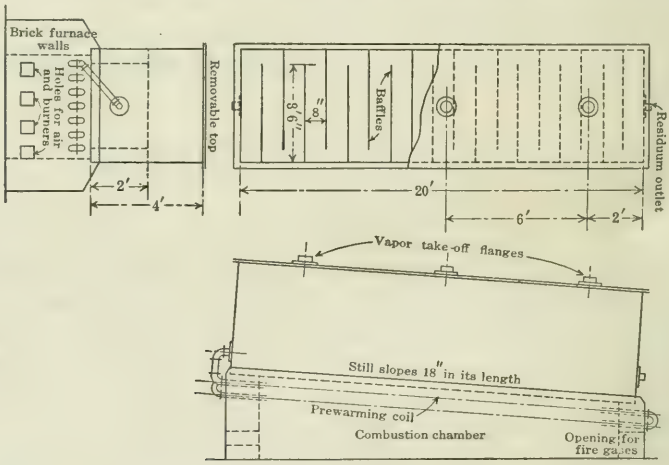
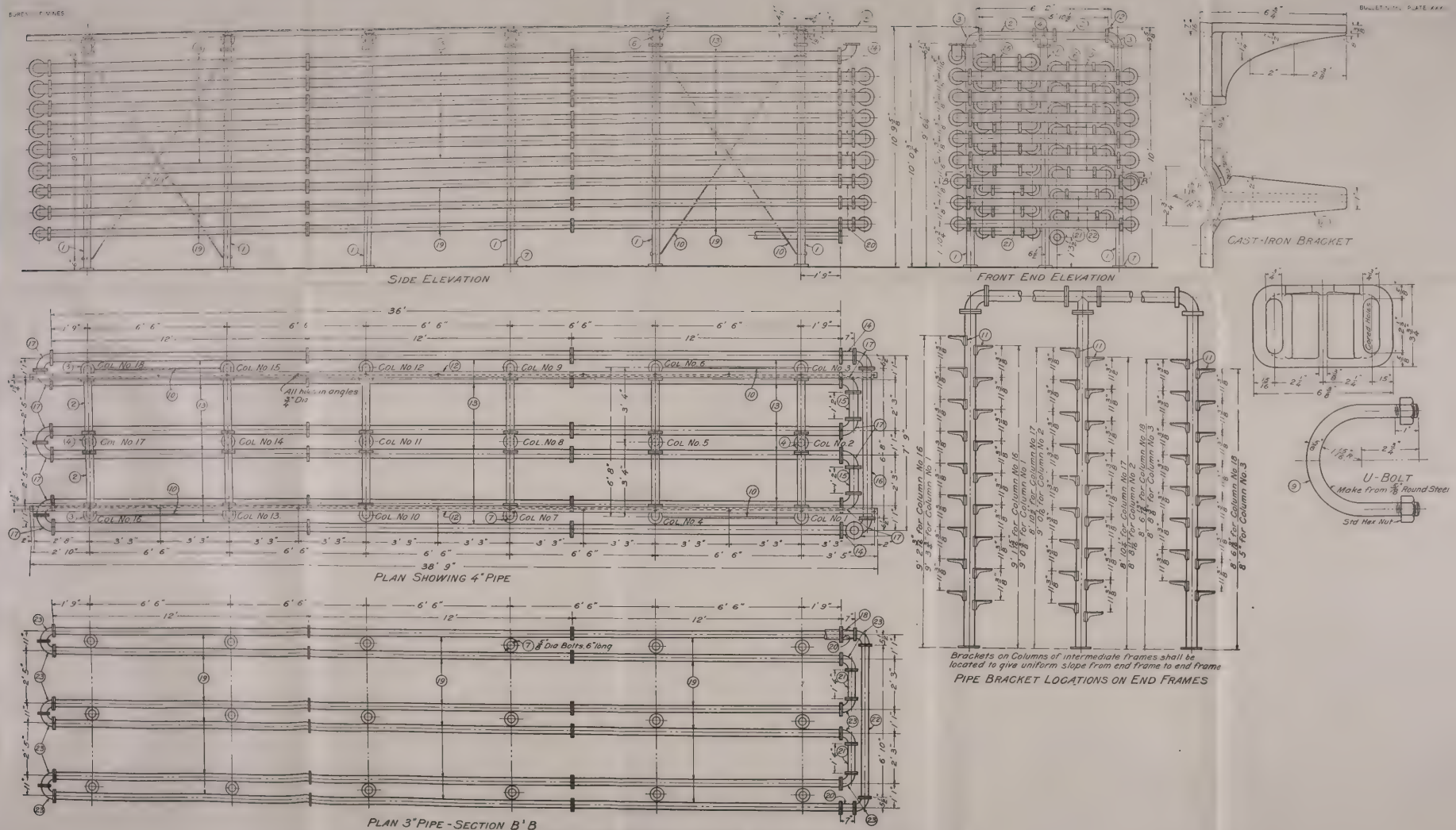


FIGURE 13.—Rectangular still, Brown-Pickering topping plant, Fullerton, Cal.

form a continuous coil. A vapor header connects these boxes in parallel on top, and a distillate header collects the condensate at the bottom. Cooling water enters at the bottom of the box and leaves at the top.

In addition to the boxes, two cooling towers about 18 by 36 feet by 16 feet in height are used. One tower contains 15 runs of 6-inch pipe each 34 feet long connected to form a continuous coil for vapors, and eight runs of 6-inch pipe each 34 feet long, similarly connected, as a cooling coil to further cool the residuum from the heat exchangers. The other tower contains the vapor coil only, composed of 13 runs of 6-inch pipe, each 34 feet long. The vapor coils are supported near the top of the tower, and the cooling water is sprayed over them and trickles down through the towers to the sump supplying the water pumps. (See fig. 14.)



DETAIL OF SPRAY CONDENSER AND SUPPORTS, DYER TOPPING PLANT, AVILA, CAL.

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HEAT EXCHANGERS.

Near the bottom of each tower four heat exchangers are supported. Each consists of a 14-inch pipe 36 feet long flanged on each end and fitted with tube sheets into which are rolled several 1½-inch tubes. Manifolds are bolted to each end and, by means of a horizontal baffle in one manifold, oil flowing through the tubes is given two passes

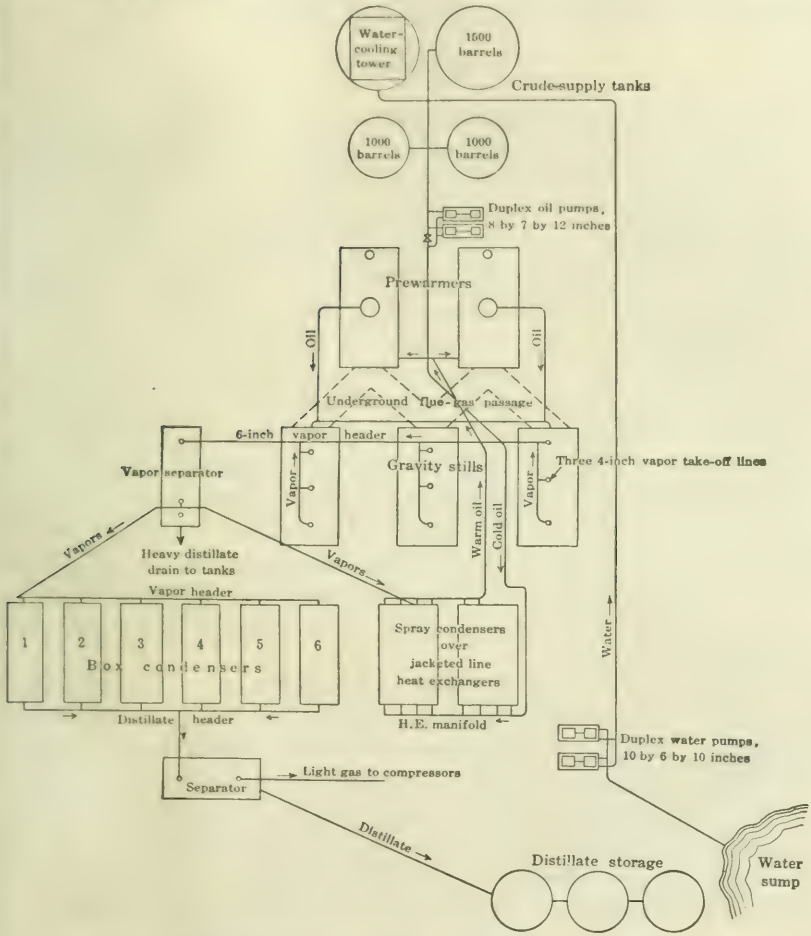


FIGURE 14.—General arrangement of Brown-Pickering topping plant, Fullerton, Cal.

in traveling through the apparatus. The residuum enters the top at one end and flows around the tubes, leaving at the bottom on the other end. The water falling over these heat exchangers assist in cooling the residuum. Plate XXXV (p. 89) shows the wooden condensers and the heat exchangers prior to the addition of the cooling-water towers.

SEPARATORS.

The separators each consist of a horizontal cylindrical shell about 6 feet in diameter and 25 feet long. Vapors enter at the top on one end and leave at the top on the other, and heavy distillates condense and are drained to storage tanks from the bottom.

A cooling tower about 16 by 16 feet by 20 feet in height surmounting a wooden tank handles the water from the condensers. The general layout of the plant is shown in figure 14.

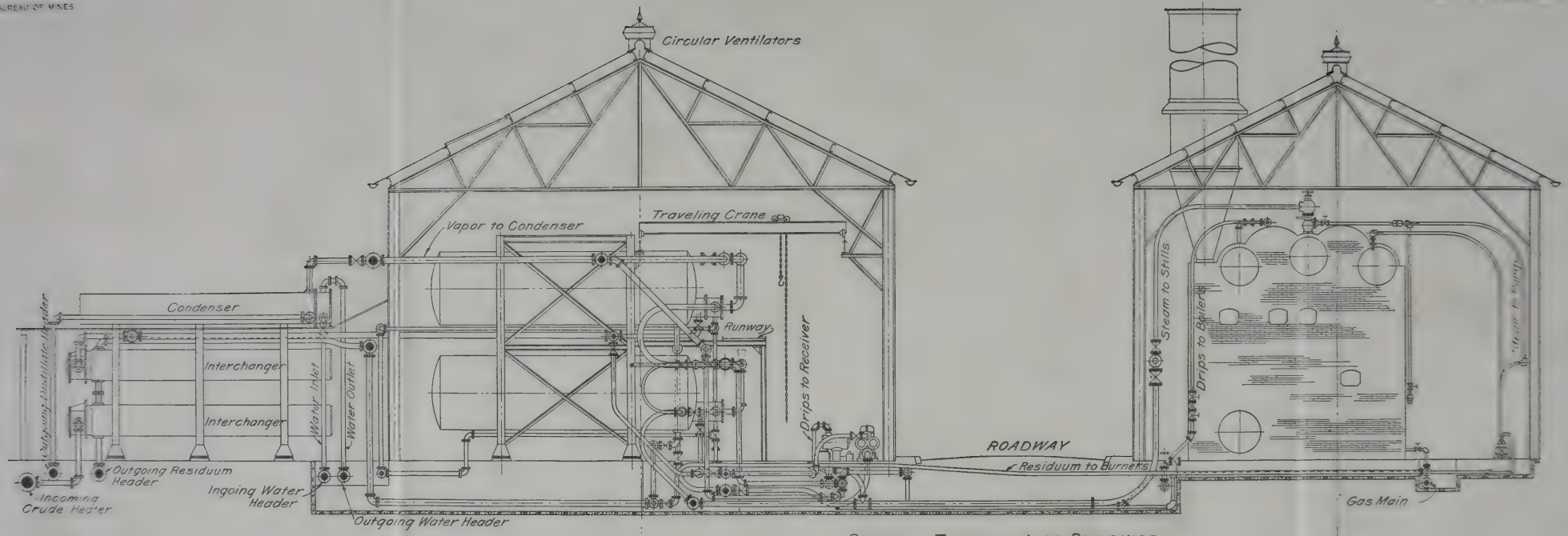
OPERATION.

Crude oil enters the plant through a Fairbanks-Morse pump, 8 by 7 by 12 inches, and is forced through the tubes of the heat exchangers which are connected by a header in parallel. From the exchangers the oil, warmed by the outgoing residuum surrounding the tubes, passes to the prewarmers, entering each near the bottom at one end. In operation the prewarmers are always full of oil at a normal pressure of about 60 pounds. The prewarmers are provided with drain lines and considerable water is separated within the apparatus. At intervals this water is drained from the prewarmers. The oil after being heated to a temperature of 200° to 210° F. (93.3° to 98.85° C.) by the waste gases from the furnaces leaves the economizers through the domes and enters a header supplying the coils below each still. These coils are directly fired, the oil within them flowing back and forth and upward to the high end of the stills. A valve is provided at the end of each coil to insure a steadiness of pressure on the coils. Oil entering the stills flows back and forth over the bottoms to the low end of each still, and is withdrawn as residuum by a pipe feeding the heat exchangers.

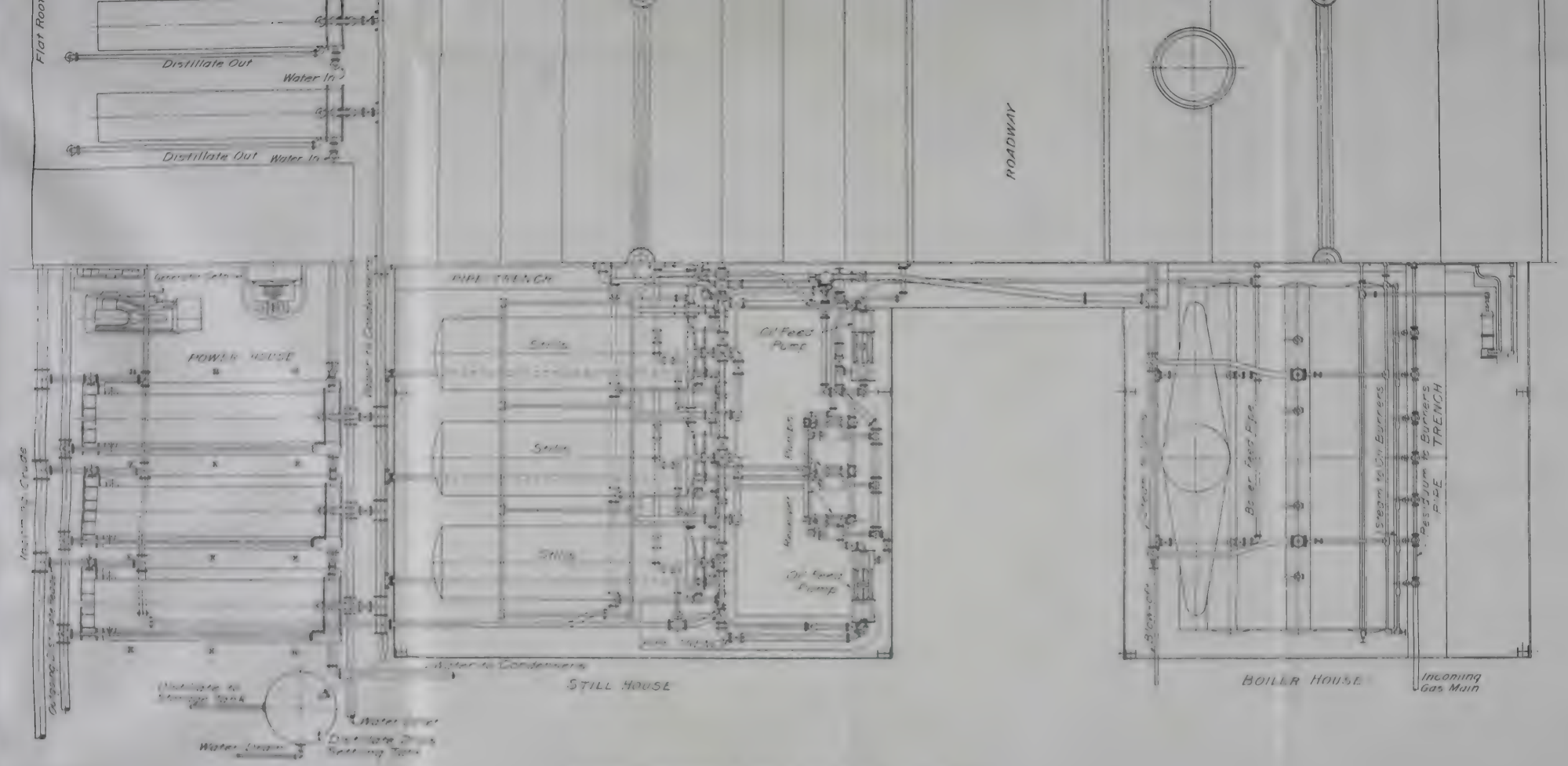
The residuum leaving the stills is pumped to the heat exchangers in parallel, heating the incoming crude, and passes then to the residuum cooling coil, being further cooled before flowing to storage. Regulation of the fire and feed controls the quality of this residual oil. The temperature of the still is maintained at about 325° F. (162.7°C.).

The vapors separate from the oil in its course through the stills and leave through 4-inch vapor take-off pipes on the top of each still. These take-off pipes are connected by a 6-inch header terminating at the vapor separator. Light vapors pass through the separator to the condensers, and heavy vapors condense and are drained from the bottom to storage. Also any foaming in the stills when a wet oil is forced through the plant can be checked at the separator, and the resulting emulsion can be diverted to tanks instead of being allowed to foul the condensers.

From the condensers the distillates enter a second vapor separator at the top. The separator is connected to a gas compressor plant,



SECTION THROUGH ℄ OF BUILDINGS



GENERAL ARRANGEMENT OF CRUDE TOPPING PLANT AVILA, CAL.

and the so-called permanent gases evolved in treating the oil vent to this plant and are condensed under pressure as a high-gravity volatile product. This product is blended with distillates for motor fuel. The distillates gravitate from the separator to storage.

The plant is being operated as a dehydrator. Normally 2,800 to 3,000 barrels of 17° B. (specific gravity, 0.9524) oil containing about 20 per cent of emulsion is run daily. From this about 175 barrels of distillate of 52° B. (specific gravity, 0.7692) is made, leaving about 2,200 barrels of residual oil. The difference represents water taken from the oil and refining loss. Though used for dehydrating, this plant is not adapted to that purpose, as a wet oil must be run very slowly to prevent foaming and consequent discoloring of the distillates. The construction of the stills does not permit operating them under pressure to hold down this foam. Gas leaving the compressor plant supplies fuel to the topper, and no attempt is made to meter the quantity used.

Records of cooling-water consumption are also unavailable, so that costs of operation can not be obtained. One stillsman on each tower operates the entire plant.

Sediment contained in the oil soon cuts the return bends on the coils below the stills, so that frequent repairs are necessary. Also the flues in the economizers often leak, and both troubles usually occasion small fires in the apparatus. However, these fires are not serious, as the volume of oil involved is not great, and the fire can be readily checked.

There are several plants of this type in use in California fields, and, when used for topping a comparatively dry oil, they have proved economical and easily controlled.

PRUTZMAN PLANT.

A Prutzman plant with a capacity of approximately 1,500 barrels a day is cleaning and topping Santa Maria emulsified oil at Betteravia, Cal. The crude oil when run in fire stills is quite frothy and contains many scale-forming elements; the method of handling it is therefore of interest.

GENERAL DESCRIPTION.

The plant consists in general of two tubular heat exchangers, two steam stills, a heater of 3-inch pipe, and a tubular boiler utilizing the flue gases from the heater. A vertical tubular condenser is also provided, and the necessary steam is supplied from the main boiler plant of the refinery.

DETAILED DESCRIPTION OF APPARATUS.

EXCHANGERS.

Each exchanger consists of a horizontal cylindrical steel shell about 20 feet long with a tube sheet fixed 2 feet from each end. Into this tube sheet 62 2-inch boiler tubes are expanded, giving the exchanger approximately 500 square feet of surface. Oil passes through the tubes, being heated by exhaust steam from the steam stills.

STEAM STILLS.

The stills are 10 by 25 foot horizontal cylindrical steel shells of about 250 barrels charging capacity. Each contains a continuous

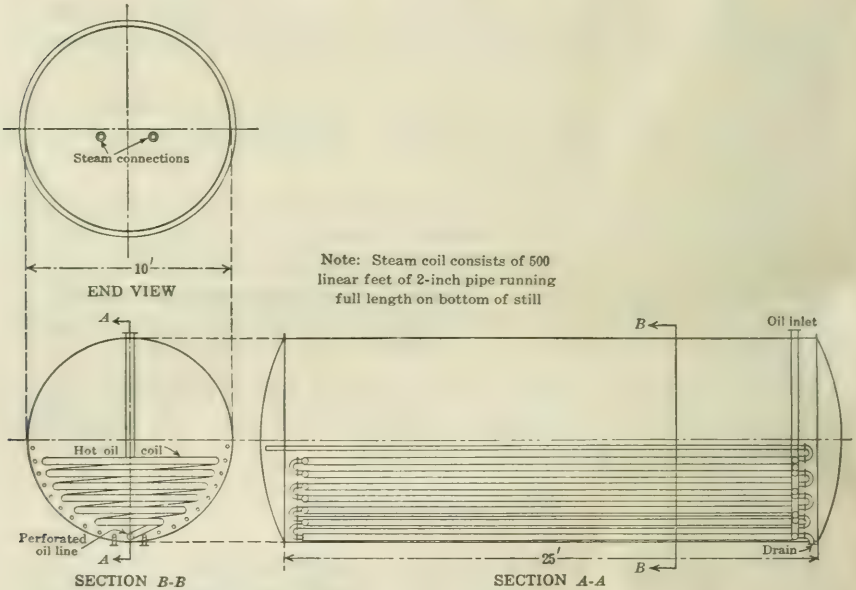
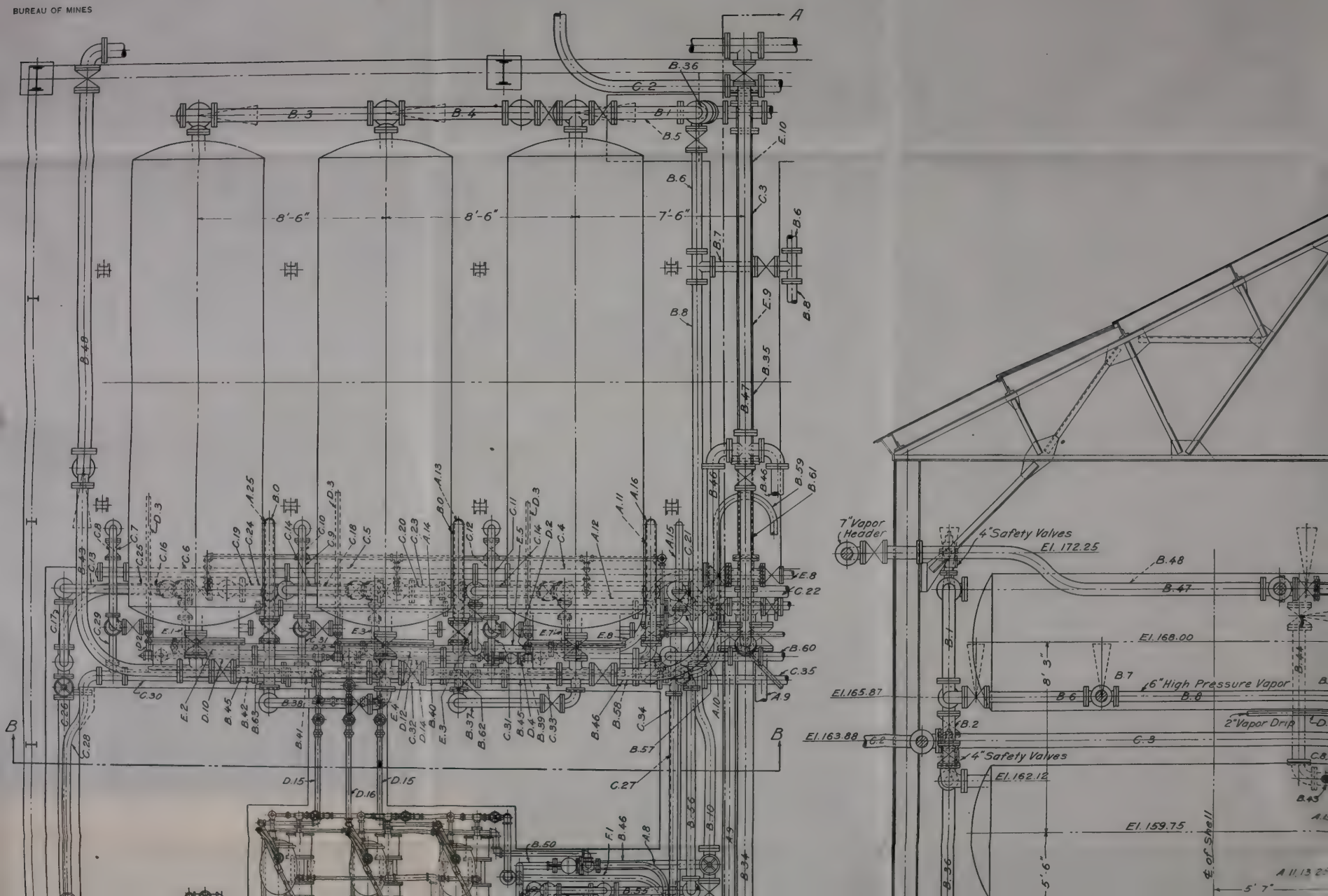
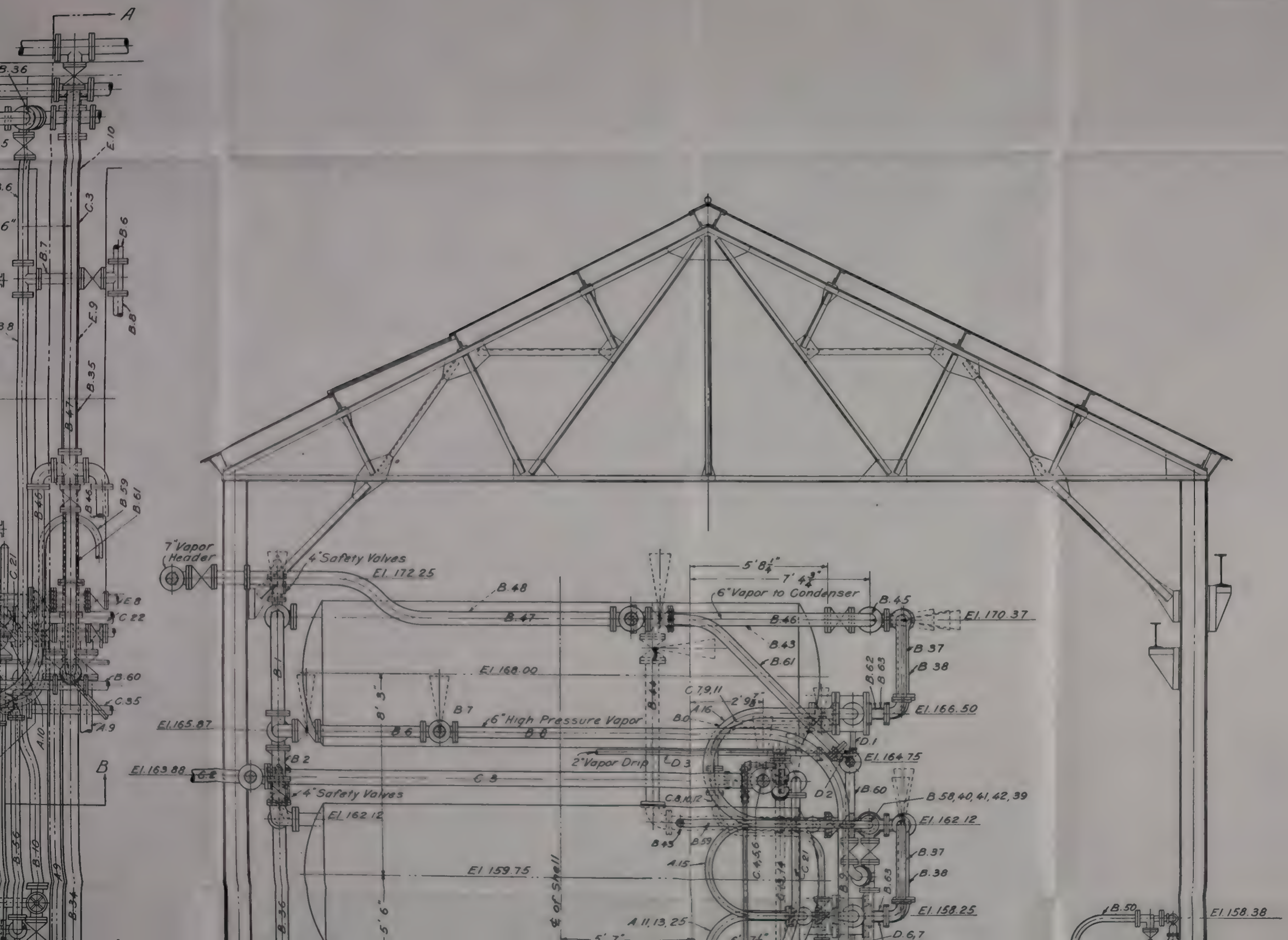


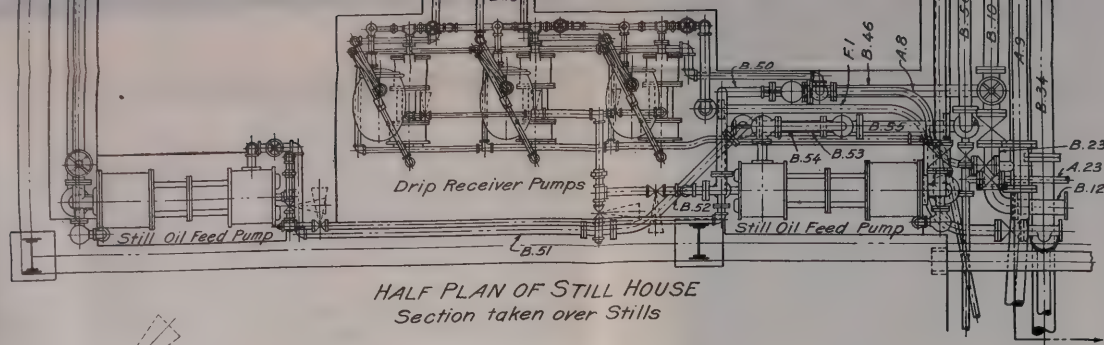
FIGURE 15.—Steam still in Prutzman topping plant, Betteravia, Cal.

steam coil of 500 linear feet of 2-inch pipe laid longitudinally across the bottom. Resting upon this coil is a square spiral coil containing the entering oil. This coil terminates in a single run of perforated pipe the length of the still on the bottom.

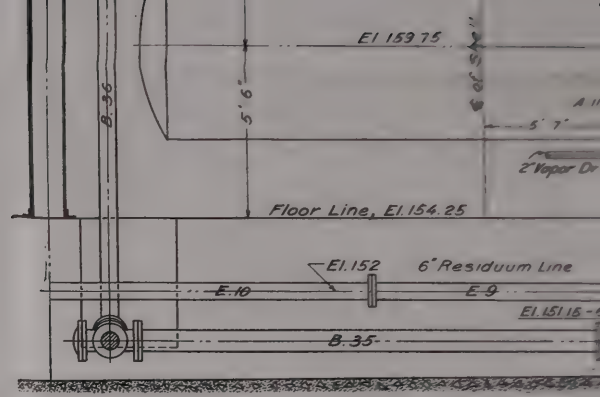
Partial distillation of the oil is effected within this coil, and owing to the confined space in the coil, priming is avoided. The stills are insulated by a 2-inch asbestos covering protected from the weather by tongue-and-groove flooring held in place by iron straps. (See fig. 15.)


A
B
8'-6"
8'-6"
7'-6"
7" Vapor Header
4" Safety Valves
El. 172.25
El. 168.00
6" High Pressure Vapor
2" Vapor Drip
El. 165.87
El. 163.88
4" Safety Valves
El. 162.12
El. 159.75
℄ of Shell
5'-6"
5'-7"
8'-3"

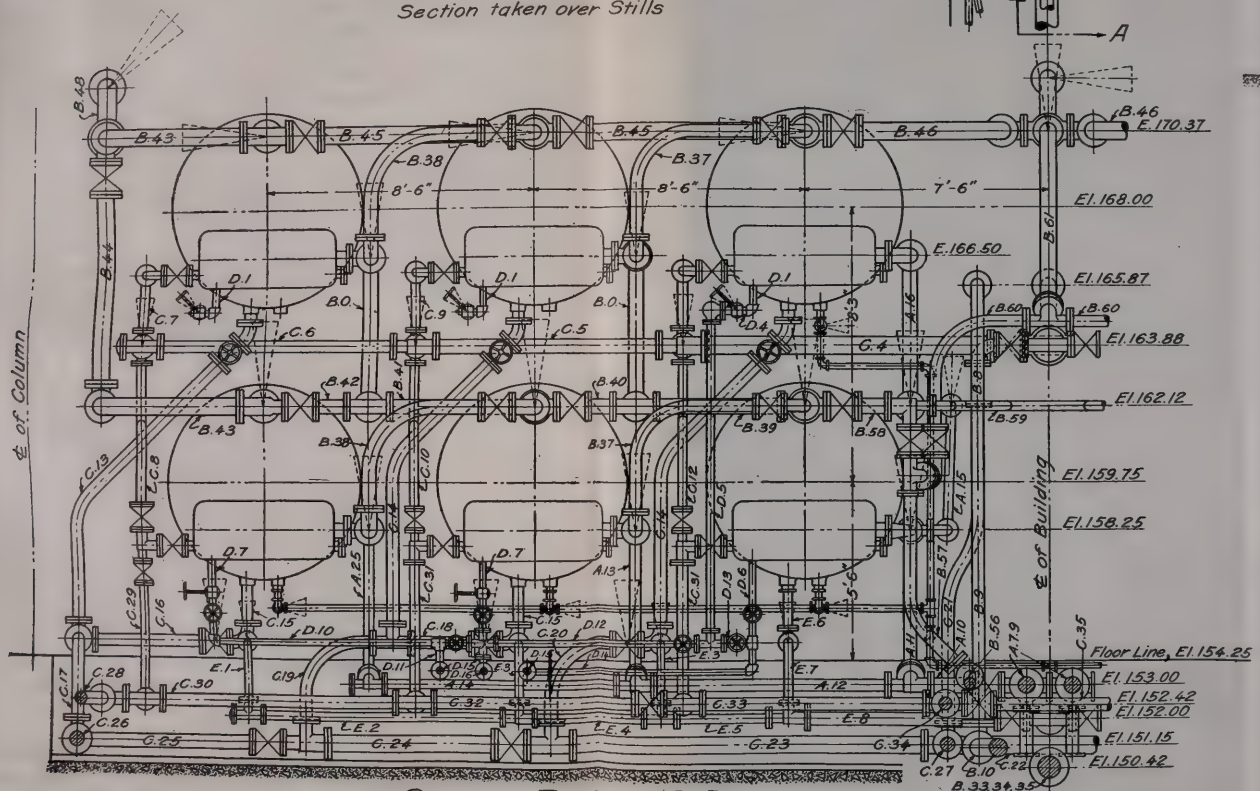

A
B
7" Vapor Header
4" Safety Valves
El. 172.25
B.48
B.47
6" Vapor to Condenser
B.45
B.46
El. 170.37
B.43
B.61
B.37
B.38
El. 168.00
El. 166.50
El. 165.87
6" High Pressure Vapor
B.7
B.6
B.8
2" Vapor Drip
D.3
El. 164.75
El. 163.88
C.3
4" Safety Valves
El. 162.12
B.60
B.58, 40, 41, 42, 39
El. 162.12
El. 159.75
℄ of Shell
El. 158.25
El. 158.38
B.50
A.11, 13, 25
5' 8¼"
7' 4¾"
8' 3"
5' 6"



HALF PLAN OF STILL HOUSE
Section taken over Stills

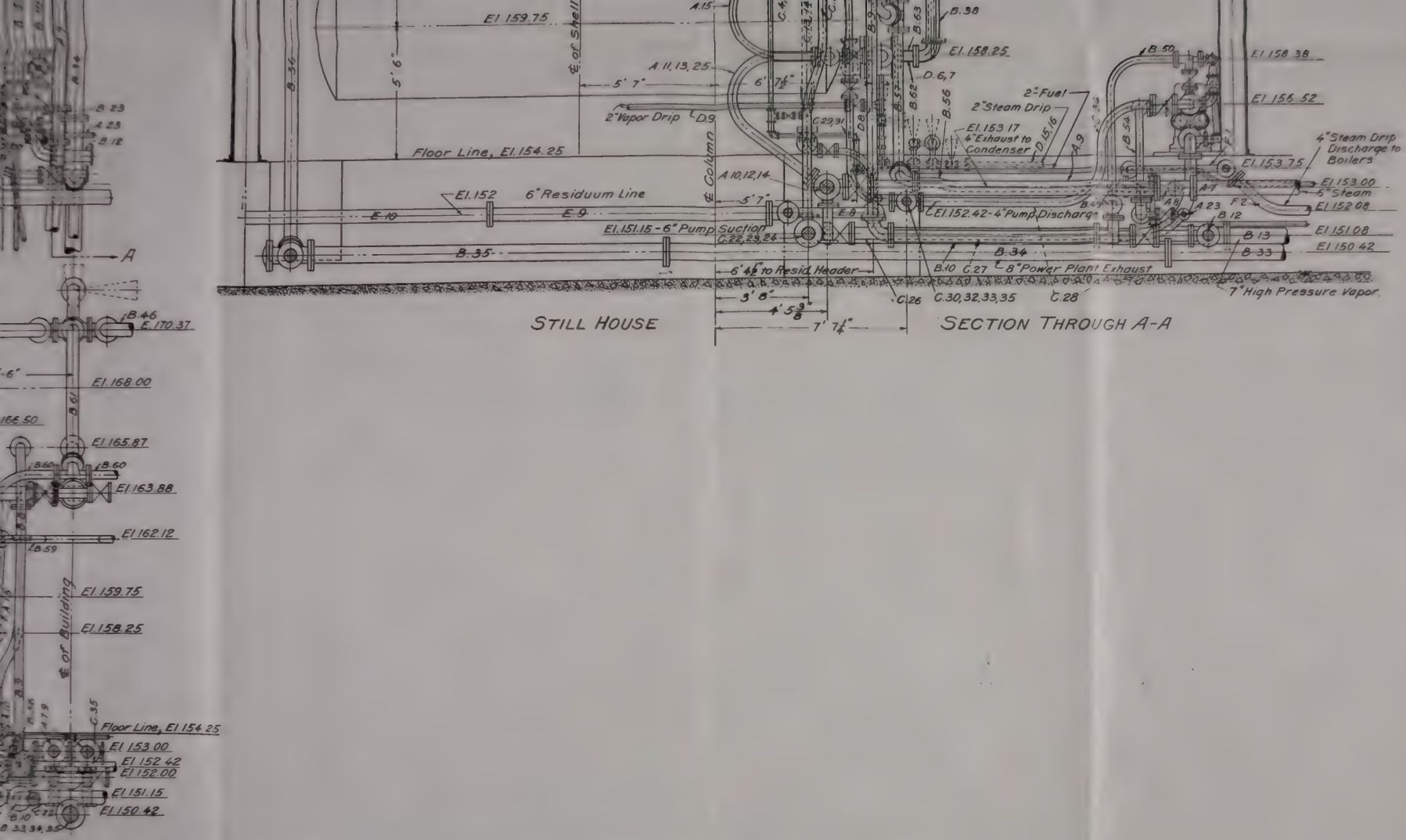


STILL HOUSE



SECTION THROUGH 'B-B'

INTERCONNECTING STILL PIPING, DYER TOPPING PLANT, AVILA, CAL. *A*, BOILER STEAM; *B*, OIL VAPOR; *C*, CRUDE OIL; *D*, DISTILLATE; *E*, R



PPING PLANT, AVILA, CAL. *A*. BOILER STEAM; *B*. OIL VAPOR; *C*. CRUDE OIL; *D*. DISTILLATE; *E*. RESIDUUM; *F*. STEAM DRIP; *G*. BLOW-OFF.

HEATER AND ECONOMIZER.

The heater (Pls. XXXVI, *A*, p. 90, and XXXVII, p. 92) comprises a rectangular brick furnace inclosing eight horizontal rows of eight 20-foot lengths of 3-inch pipe connected together to form a continuous coil. This coil is supported by the brickwork 5 feet above the furnace floor, with the flanged connections on the outside, so that 18 feet of each pipe is exposed to the fire.

The oil enters at the bottom row of pipes and leaves at the top, and the flue gases make one pass through the heater to the economizer.

The economizer is a tubular boiler having approximately 1,460 square feet of heating surface. The oil surrounds the tubes and the flue gases make one pass through the tubes to the stack.

CONDENSER.

The condenser (fig. 16) is a vertical cylindrical shell about 6 feet in diameter and 22 feet high, with a tube sheet riveted 3 feet from each end. Into the tube sheets 97 4-inch tubes 16 feet long are expanded, giving a surface of 1,550 square feet. The bottom of the condenser is closed with a riveted cover plate, and the top is left open. Cooling water flows through the tubes, whereas the vapors enter the top of the condenser through a 4-inch flange and leave as condensate at the bottom.

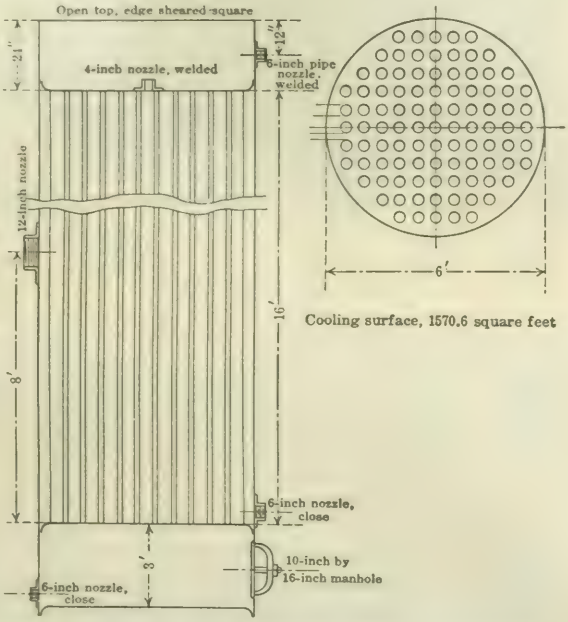


FIGURE 16.—Vertical tubular condenser, Prutzman topping plant.

OPERATION.

The cold crude is pumped by a rotary pump through the exchangers in series, passing through the tubes and being heated by the steam from the steam stills. Crane tilt traps return this steam to the boilers after it passes the exchangers.

From the exchangers the oil at a temperature of about 160° F. (71.1° C.) goes to the economizer; it enters at the bottom and leaves from the top at a temperature approximating 205° F. (96.1° C.). Thence it passes to No. 1 still, entering through the spiral coil and leaving the still at about 215° F. (101.6° C.). Some gasoline vapors and a little water leave No. 1 still through the 8-inch vapor line to the condensers.

The residue is forced by a Kinney rotary pump to the heater, passing upward through the coil and leaving for No. 2 still at about 270° F. (132.4° C.). No. 2 still practically operates as a vapor separator, no rise in temperature being noted.

The steam is supplied to the stills at about 100 pounds boiler pressure. Vapors from No. 2 still join those from No. 1 still and pass to the same condenser. The bottoms from No. 2 still are pumped to the refinery for further reduction.

The following tabulation is a six months' record of plant operation in 1917:

TABLE 19.—*Record of plant operation, 1917, Prutzman topping plant.*

Date.	Gross crude run.	Gravity of crude.		Water content of crude.		Distillate made.	Gravity of distillate.		Residuum made.	Gravity of residuum.		Refining loss.
		°B.	Specific gravity.	Barrels.	Per cent.		°B.	Specific gravity.		°B.	Specific gravity.	
	Barrels.					*Barrels.*			*Barrels.*			*Barrels.*
January	57,350	22.5	0.919	6,200	11.2	16,337.0	52.0	0.771	34,813	16.2	0.958	.....
February	46,200	21.4	.925	10,600	22.8	8,776.0	52.0	.771	26,824	15.5	.963	.....
March	49,011	22.9	.917	6,400	13.8	14,835.0	52.0	.771	27,776	15.4	.963	.....
April	52,380	23.0	.916	5,400	10.3	14,299.6	52.0	.771	30,690	14.9	.966	1,9..
May	60,729	23.4	.914	6,480	10.5	18,559.0	52.0	.771	34,658	14.9	.966	1,090
June	55,860	22.8	.917	6,670	12.0	14,166.7	52.0	.771	32,160	14.7	.968	2,864

No fuel record for either the heaters or the boilers is kept, because the company is burning natural gas and waste oil for which they have no market. The plant is handling the wet oil satisfactorily and probably efficiently, as considerable effort is made to recover waste heat.

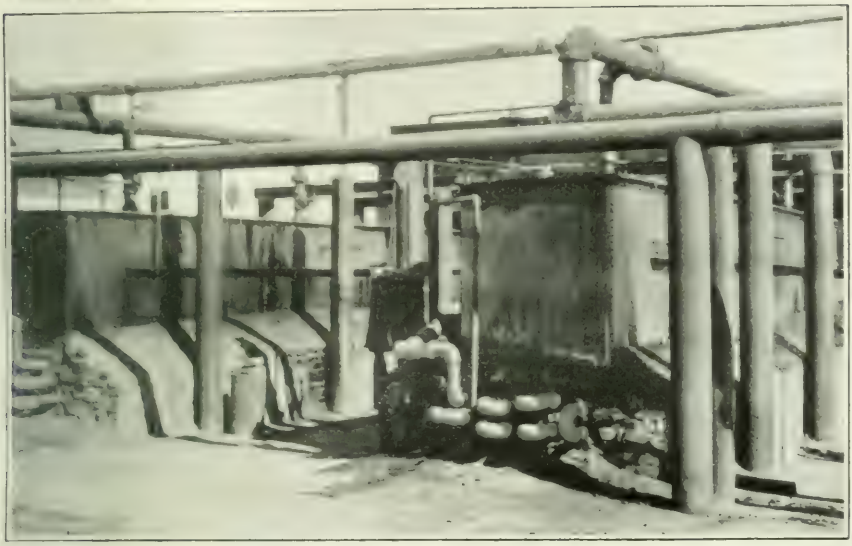
The exchanger construction might be improved as well as that of the heater, though the economizer reduces the stack gases to a reasonable temperature.

TRUMBLE TOPPING PLANTS.

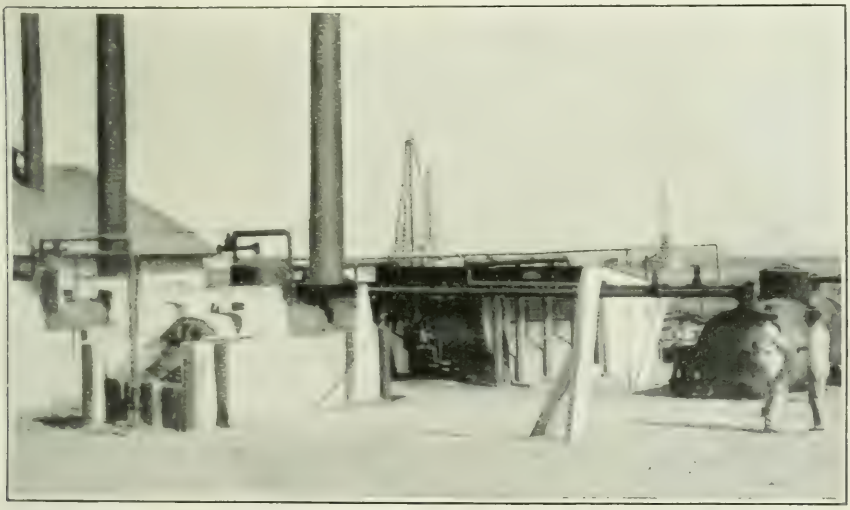
FELLOWS PLANT.

The first Trumble plant to achieve commercial success was built in January, 1911, at Fellows, Kern County, Cal.

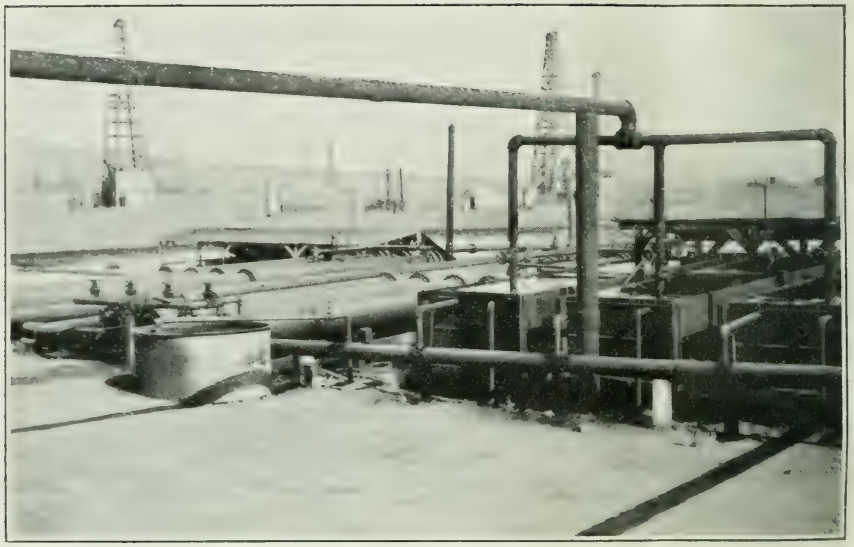
Its purpose primarily was to raise the flash of the light oil from the North Midway field, to remove any excess water content, and thus to produce a safe homogeneous residual fuel oil. The production of the resulting distillate was incidental to this purpose, but proved to be a



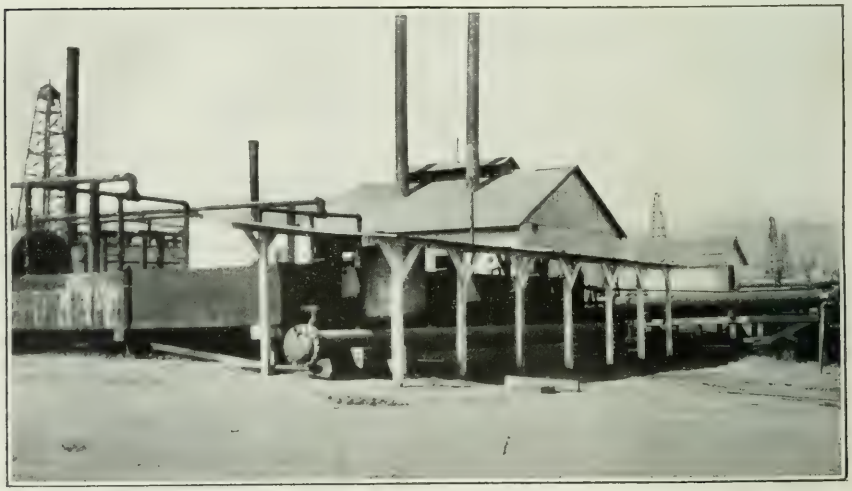
A. VIEW OF BROWN-PICKERING STILLS SHOWING HEATING COILS UNDERNEATH.



B. GENERAL VIEW OF BOILER PREWARMERS (IN LEFT FOREGROUND) STILLS (IN MIDDLE), AND VAPOR SEPARATOR (AT RIGHT), BROWN-PICKERING PLANT.



A. CONDENSERS AND HEAT EXCHANGERS. BROWN-PICKERING PLANT. NOTE THE OVERHEAD VAPOR LINE IN THE FOREGROUND.



B. REAR VIEW OF THE CONDENSERS AND EXCHANGERS. BROWN-PICKERING PLANT.

large factor in the success of the plant (see Table 23, p. 103). The oil treated had an average gravity of 21° B. (specific gravity, 0.928) and contained 2 to 3 per cent of water. The plant was operated continuously until July, 1913, when the operating company contracted for the disposal of its production to a refinery and dismantled the plant.

GENERAL DESCRIPTION.

The construction in general is as follows:

One battery of two heaters, each consisting of six 12½-inch pipes 20 feet long connected end to end by 4-inch elbows and nipples into reducing flanges, feed a single vertical separating chamber called the evaporator.

Two separator boxes of the "first type" (see fig. 19, p. 96) are provided for rerunning the condensate from the jacketed line condensers by means of the heat recovered from the hot vapors and residuum leaving the plant.

In addition, about 2,000 feet of jacketed lines is used for cooling the distillate and exchanging heat between incoming cold oil and outgoing residuum. A small water-cooling tower handles the water used in the jacketed line coolers.

Figure 17 shows the general arrangement of the plant, and the evaporator, separators, etc., are described in the discussion of the Vernon plant following.

In the construction all possible advantage was taken of available material at hand, the evaporator in particular being constructed of two discarded boiler shells riveted together after one head had been removed. The jacketed lines were constructed entirely of discarded well casing of suitable sizes. The mean area of the total heating surface exposed to the fire in both heaters was 777.6 square feet.

OPERATION.

The crude oil is pumped through the jacketed line heat exchanger, being heated by the outgoing hot residuum; thence it passes to the right and left heater pipes and to the top of the evaporator. By means of baffles the hot oil is forced in a thin film down the sides of the evaporator, which is heated by the outgoing flue gases. A vertical perforated pipe supporting the baffles collects the vapors coming from the oil and delivers them to the drum head of the first separator. In separator 1 the vapors pass through six 3-inch pipes, heating the surrounding distillates, and enter a jacketed line cooler whence, being condensed, they return to the liquid chamber of separator 1 for redistillation.

In separator 2 the hot residuum drawn from the bottom of the evaporator is used as a heat medium in the 3-inch pipes for rerunning the bottoms from separator 1 before passing to the heat exchanger.

By means of the two vapor compartments in each separator it is possible to obtain four fractions which, together with the bottom distillate from separator 2, give five products of different gravity.

In practice the first top from separator 1 is condensed for gasoline, the second top of separator 1 and the first top of separator 2 are

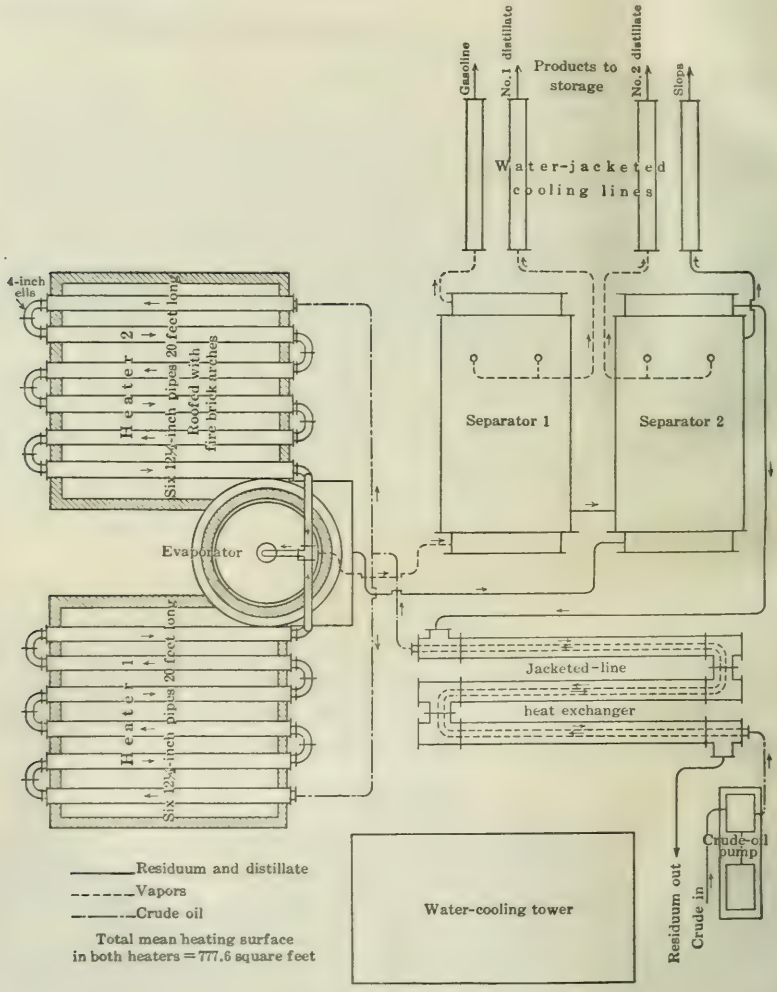
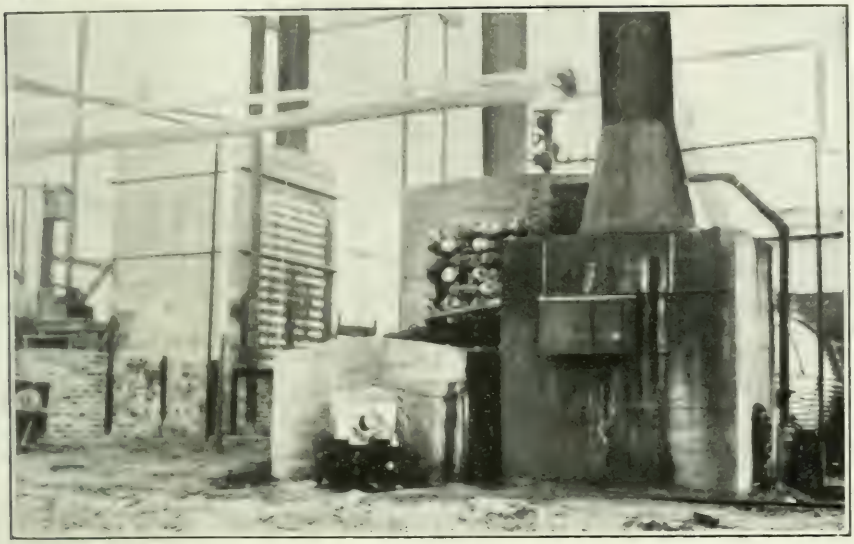


FIGURE 17.—General arrangement of Trumble plant at Fellows, Cal.

combined and condensed for No. 1 distillate, and the second top of separator 2 and the bottom of separator 2 are condensed for No. 2 distillate.

COST OF OPERATION.

Table 20, following, gives the performance of the plant from March 1, 1912, to August 1, 1913, and the totals listed below furnish an average basis for the cost data following.



A. PIPE RETORT AND PREWARMERS. PRUTZMAN PLANT.

B. 48-INCH AND 30-INCH CONDENSERS WITH JACKETED LINE COOLERS IN FOREGROUND. VERNON TRUMBLE PLANT.

TABLE 20.—*Record of operation of Fellows topping plant.*

Month.	Delivery to refinery.	Stock, first of month.	Delivery shipments.					Stock, end of month.	Refining loss.
			Fuel used.		Total.	Residuum.	Tops.		
			Oil.	Gas.					
1912.	*Barrels.*	*Barrels.*	*Barrels.*	*Cubic feet.*	*Barrels.*	*Barrels.*	*Barrels.*	*Barrels.*	*Barrels.*
March	140,361.2	9,026.0	1,889	(a)	134,348.6	123,717.2	9,881.4	11,814.0	3,174.5
April	140,005.5	11,814.0	1,797	(a)	134,815.8	127,218.1	7,617.7	11,902.0	5,101.7
May	153,870.9	11,902.0	1,421	(a)	142,628.5	131,300.7	9,821.0	17,278.0	5,866.4
June	150,754.7	17,278.0	854	(a)	147,852.5	134,405.9	11,346.0	13,014.6	7,385.4
July	148,221.7	13,014.6	444	(a)	137,972.5	.....	.....	13,852.3	9,411.5
August	146,162.0	13,852.3	950	(a)	135,171.3	118,089.0	17,082.3	18,304.7	6,638.2
September	160,145.9	18,304.7	960	(a)	154,115.1	139,774.8	14,340.3	17,508.4	6,827.0
October	156,793.7	17,508.4	1,004	(a)	148,348.6	133,407.2	14,941.4	17,018.0	8,935.4
November	125,093.6	17,018.0	551	(a)	120,207.8	104,750.7	15,457.1	13,324.4	8,569.3
December	150,872.2	13,334.4	606	(a)	144,520.3	121,889.7	12,630.6	16,353.3	3,332.9
1913.									
January	149,718.6	16,353.3	1,203	3,423,900	146,481.6	.....	.....	14,947.8	4,642.5
February	138,391.2	14,947.8	1,241	1,710,500	135,858.1	114,798.7	21,059.4	10,382.0	6,269.9
March	179,057.9	10,382.0	1,383	2,231,000	159,882.2	134,737.1	25,145.1	19,339.0	8,844.0
April	169,087.5	19,330.0	483	9,287,151	166,617.7	139,892.1	26,725.6	15,698.0	5,618.8
May	167,086.4	15,698.0	359	10,030,551	155,696.9	130,046.1	25,650.8	19,003.0	7,797.5
June	164,185.3	19,003.0	171	11,159,151	150,575.6	128,600.3	21,975.3	26,756.0	5,686.6
July [b]	143,829.6	26,756.0	47	11,903,151	149,573.8	127,137.6	22,436.2	13,867.0	5,097.8
Total	2,583,638.90	.....	15,363	49,745,404	.....	.....	.....	.....	109,209.4

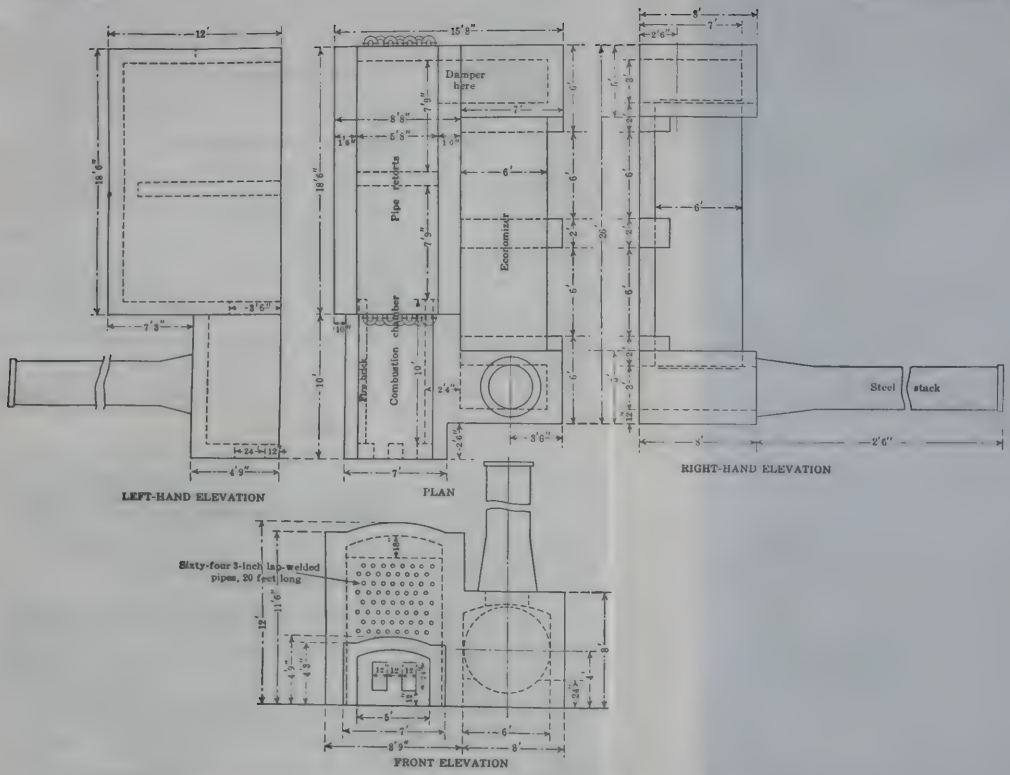
[a] Not metered.

[b] Plant ceased operation.

TABLE 20.—*Record of operation of Fellows topping plant*—Continued.

Month.	Refinery operation.		Production.							Operating cost, labor, and materials.
	Unit 1.	Unit 2.	Residuum.	Gasoline.		No. 1 distillate.		No. 2 distillate.		
	Days.	*Days.*	*Barrels.*	*Barrels.*	*Per cent.*	*Barrels.*	*Per cent.*	*Barrels.*	*Per cent.*	
1912.										
March	1	30	126,932.75	34.05	0.02	7,609.9	5.4	2,609.9	1.85	$1,571.50
April	½	29	125,330.1	47.14	.034	8,205.1	5.86	1,341.4	.958	610.00
May	1	30	136,348.7	49.76	.03	6,619.5	4.3	3,487.0	2.25	577.00
June	3½	26½	129,673.0	45.83	.03	7,883.1	5.23	4,100.6	2.71	560.00
July	31	31	.....	39.29	.026	8,334.3	5.62	6,519.8	4.4	673.27
August	31	30	119,718.8	51.59	.035	8,334.3	5.7	6,519.8	4.4	773.56
September	29	28	138,203.8	47.10	.029	8,534.6	5.3	6,473.6	4.04	317.37
October	29½	31	130,028.0	49.76	.031	8,786.3	5.6	8,994.5	5.73	879.62
November	25	25½	102,094.7	29.86	.023	5,341.8	4.27	[a] 4,889.7 [b] 4,157.8	[a] 3.9 [b] 3.3	1,754.99
December	30½	28½	112,630.2	32.76	.022	10,484.6	6.9	2,540.1 11,861.5	1.68 7.86	986.07
1913.										
January	31	30	120,514.3	41.90	.028	10,333.7	6.9	14,187.2	9.47	1,438.16
February	26	23	110,131.8	41.91	.03	10,141.1	7.3	10,977.5	7.93	832.40
March	31	31	142,065.1	20.95	.017	12,534.3	7.0	14,209.8	7.93	613.63
April	27	30	136,675.2	52.38	.03	11,644.2	6.88	14,613.9	8.64	704.25
May	31	26	133,970.2	26.19	.015	10,390.6	6.2	14,614.9	8.75	695.46
June	3	27	134,016.4	44.52	.027	9,073.4	5.5	15,194.3	9.25	582.49
July [c]	31	24	122,754.7	39.29	.027	2,593.1	5.28	11,297.7	7.85	551.20
Total	.....	.....	1,991,086.95	693.87	.....	146,844.30	.....	158,591.0	.....	14,120.97

[a] 45° distillate. [b] 40° distillate. [c] Plant ceased operation.



PLAN AND ELEVATIONS OF HEATER AND ECONOMIZER, PRUTZMAN TOPPING PLANT, BETTERAVIA, CAL.

Miscellaneous data relating to operation of Trumble plant at Fellows, Cal.

Total oil run, barrels	2,583,638.9
Total fuel consumed, B. t. u. (1 pound of oil=18,500 B. t. u.; 1 cubic foot of gas=1,000 B. t. u.)	141,063,844,150
Total gasoline, barrels	693.9
No. 1 distillate produced, barrels	146,844.3
No. 2 distillate produced, barrels	158,591
Total loss, barrels	109,209.4
Total cost of operation, not including cost of fuel	$14,120.97
Total days (24 hours)	421.1
Total cost of plant [a]	$10,000

Data covering treatment of 1 barrel of oil.

Fuel consumed:	
British thermal units	54,598.9
Per cent	[b] 1.4
	.92
Loss:	
Barrels	0.042
Per cent	4.2
Distillate produced:	
Barrels	0.118
Per cent	11.8
Cost per barrel, including operating cost, fuel, and loss:	
Crude ... cents	2.74
Distillate ... do	23.0
Royalty per barrel of crude ... do	1.5

Total receipts.

1,991,086.95	barrels residuum at 50 cents per barrel	$995,543.47	
693.9	barrels gasoline at $4.20 per barrel	2,914.38	
146,844.3	barrels No. 1 distillate at $1.85 per barrel	271,661.95	
158,591	barrels No. 2 distillate at $1.10 per barrel	174,450.10	
	Total receipts		$1,444,569.90

Total disbursements.

Total cost of fuel at 50 cents a barrel, or its equivalent	$11,884.74	
Total operating cost	14,120.97	
2,583,638.9 barrels of crude at 50 cents a barrel	1,291,819.45	
Total interest at 6 per cent annually	1,800.00	
Total cost of plant	10,000.00	
Total refining loss at 50 cents a barrel	44,256.42	
Royalty on patent rights, 2,583,638.9 barrels at 1.5 cents per barrel	38,754.58	
Total disbursements		1,412,636.16
Net profit in treating the oil		31,933.74

[a] As it operated practically three years, depreciation is one-third of that amount per annum.

[b] The figure of 1.4 per cent is an average for the period during which the gas fuel was metered and is probably the more reliable of the two.

VERNON PLANT.

During the year 1912 a plant of the Trumble type was constructed at Vernon, near Los Angeles, the terminal point of the building company's 8-inch oil line from the Midway field in Kern County. It had been completed and commenced operation in May, 1913.

The purpose of the plant was to remove the light valuable fractions from the oil, and prepare a fuel residue that would meet specifications. All incoming oil was topped, and the residuum shipped by cars, or pumped to the seaport shipping point, San Pedro.

GENERAL DESCRIPTION.

The plant as originally built consisted of two batteries, each with two heaters discharging into a single separating chamber called an evaporator. Each battery was equipped also with two separator boxes 6 by 14 feet by 40 inches, three 48-inch heat exchangers, two 48-inch first-run vapor condensers, five 30-inch rerun vapor condensers, and several jacketed line coolers for cooling the distillates on their way to storage from the condensers. Plates XXXVI, *B* (p. 90), XXXVIII, *A*, and XXXVIII, *B*, show this general arrangement.

DETAILED DESCRIPTION OF APPARATUS.

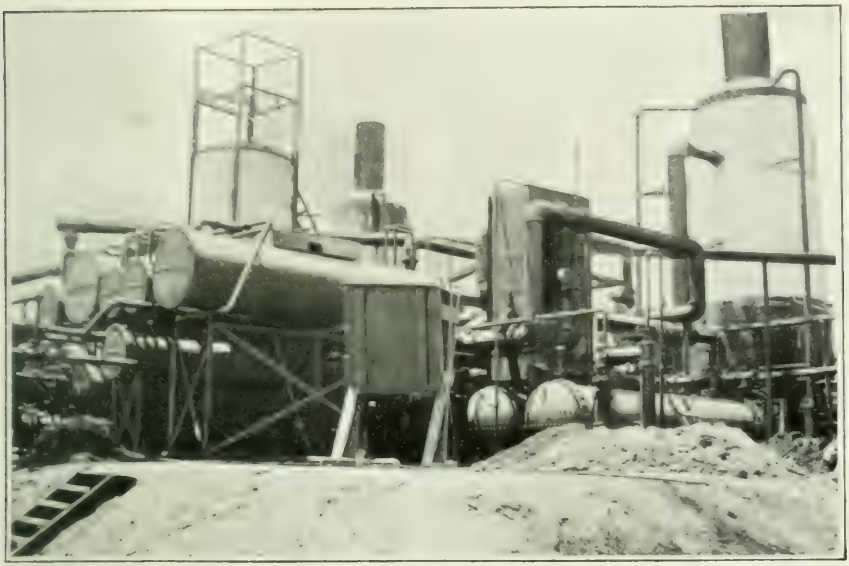
HEATERS.

The two heaters each consisted of six 12-inch standard pipes 20 feet long laid parallel to each other and resting at each end on the heater brickwork. The ends of these pipes were fitted with reducing flanges and connected by 4-inch extra heavy ells and nipples to furnish a continuous path for the flow of the oil under fire to the evaporator. At one end of the heaters 1½-inch vent pipes were tapped into the reducing flanges and connected together by a header entering the evaporator. They removed the gases which, if confined, might have caused local superheating and sagging in the large pipes.

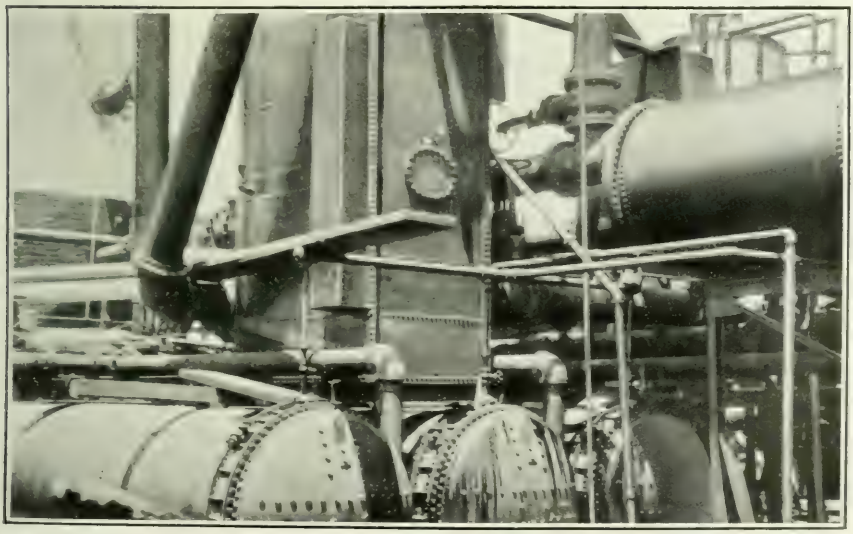
As shown in Plates XXXVIII, *A*, XXXVIII, *B*, and XXXIX *A* (p. 97), the pipes were entirely exposed to the direct fire in the furnace, only the fittings outside the brickwork permitting any loss from radiation.

EVAPORATOR.

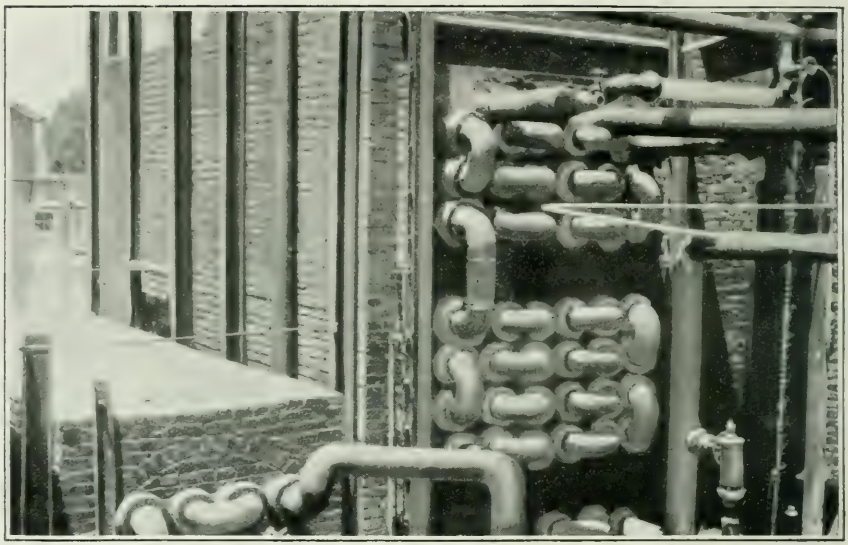
The evaporator consisted of a vertical steel cylinder, 6 feet in diameter by 25 feet in height, with an integral convex head on the bottom and a removable convex head on the top. On the top a 6-inch flange was provided for incoming heated oil, and at the bottom an 8-inch flange for outgoing residuum. The cylinder was incased with a concentric brick wall of approximately 1 foot greater inside diameter, an annular space between the shell and the brickwork being left for the passage of the flue gases from the two adjacent



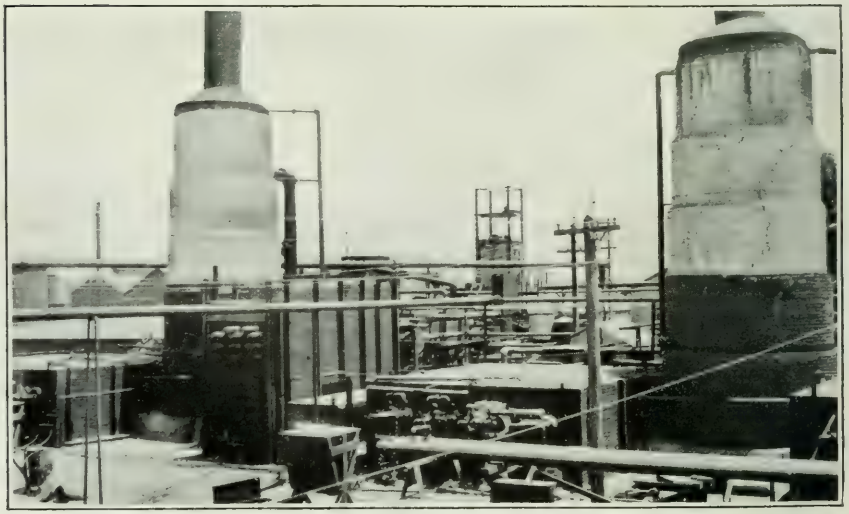
A. SIDE ELEVATION OF THE CONDENSER INSTALLATION, SHOWING DEPHLEGMATOR AND HEAT EXCHANGERS. VERNON TRUMBLE PLANT.



B. CLOSE VIEW OF DEPHLEGMATOR AND HEAT EXCHANGERS. VERNON TRUMBLE PLANT.



A. SECOND TYPE OF HEATER. VERNON TRUMBLE PLANT.

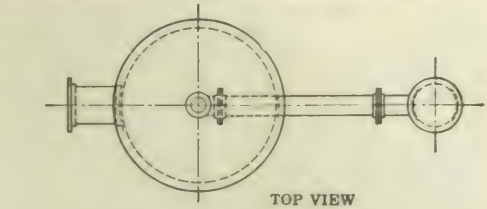


B. GENERAL VIEW OF PIPE RETORTS AND EVAPORATORS. VERNON TRUMBLE PLANT.

heaters. A short stack surmounted the brickwork at the evaporator top for the removal of these gases.

Inside the evaporator a vertical 12-inch pipe supported several circular umbrella-shaped baffles extending to within an inch of the inside face of the shell. Below each baffle perforations were made in the vertical pipe, and three 10-inch horizontal take-off lines terminating in a 16-inch header outside the brickwork conducted the vapors separated in the evaporator to the separators and condensers (see fig. 18).

The separators were rectangular steel boxes 14 feet long, 6 feet wide and 40 inches high, with a manifold at each end into which the heating pipes were fitted by means of short stuffing boxes. A horizontal partition divided the upper one-third of the box into a vapor chamber which in turn was divided by a vertical longitudinal partition into two compartments. Five vertical longitudinal partitions divided the lower part into six equal compartments each containing one 3-inch heater pipe near the bottom connected to the manifolds at either end. The distillates entering at one side to be fractionated were distributed through holes at successive levels in each partition to each compartment, from which they passed to the separator bottoms at the opposite side.



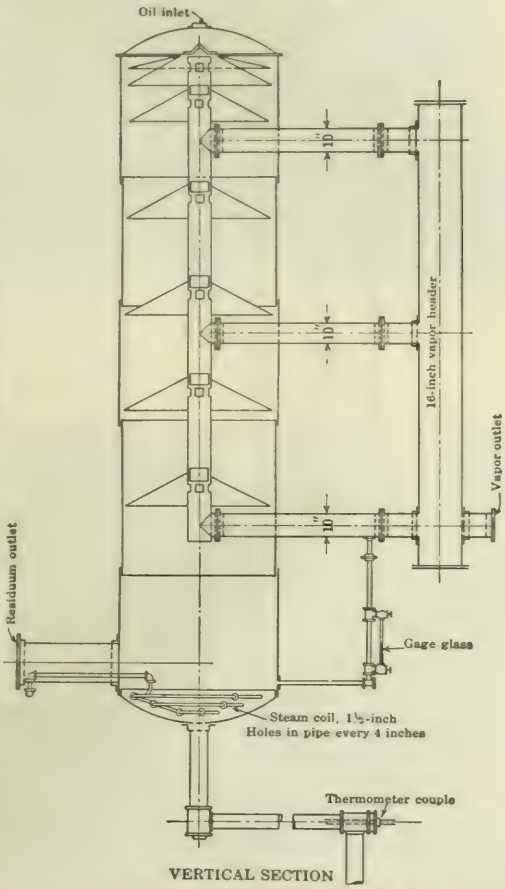


FIGURE 18.—Evaporator in Trumble plant at Vernon, Cal. Lower view, vertical section; upper view, top. Evaporator is 6 feet in diameter, 25 feet high, and has a heating surface of 471 square feet.

Vapors evolved in each compartment entered the chambers above and were led away by the vapor lines provided. The top of the separator was water jacketed so that any heavy distillates carried into the vapor chambers condensed and returned to the lower com-

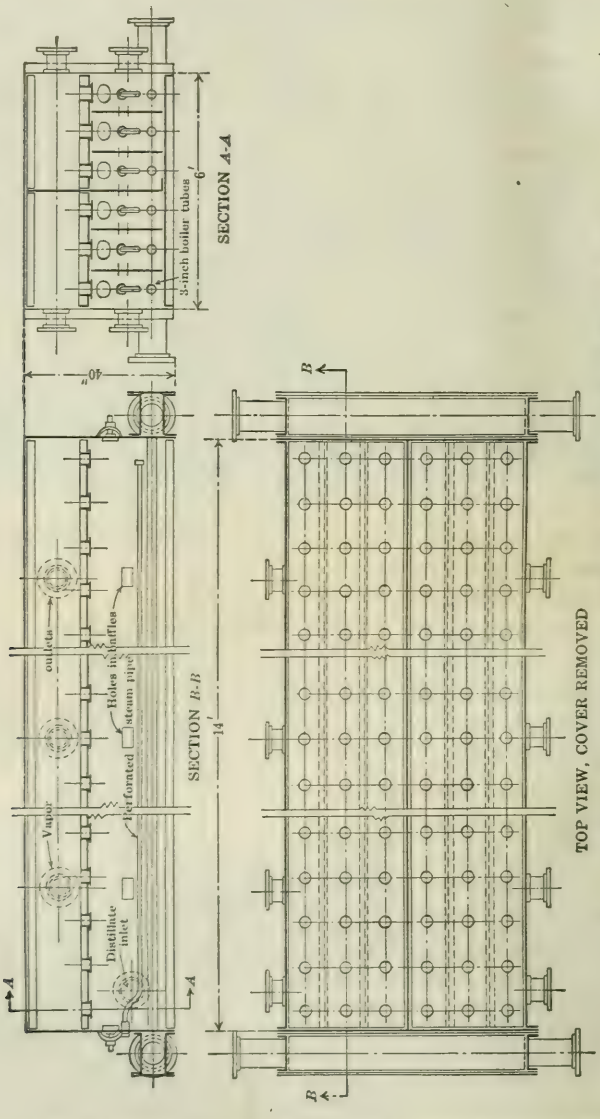
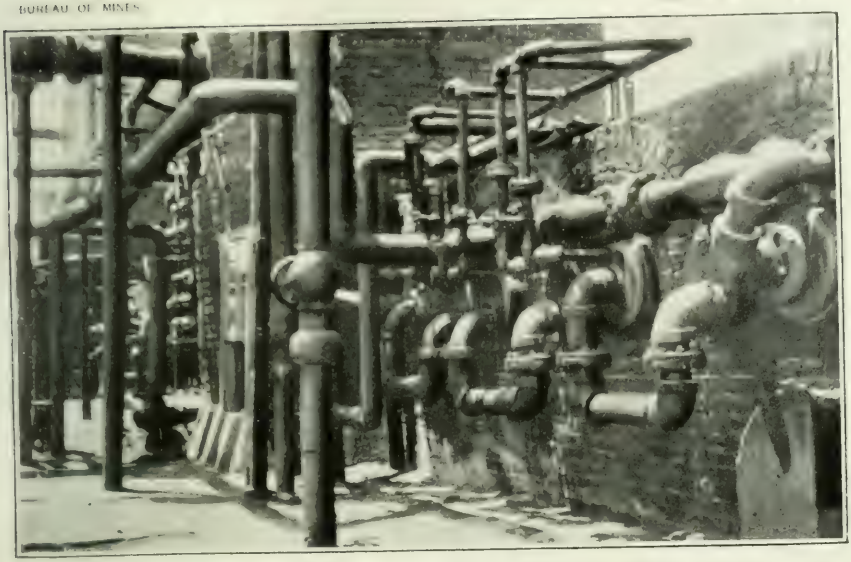
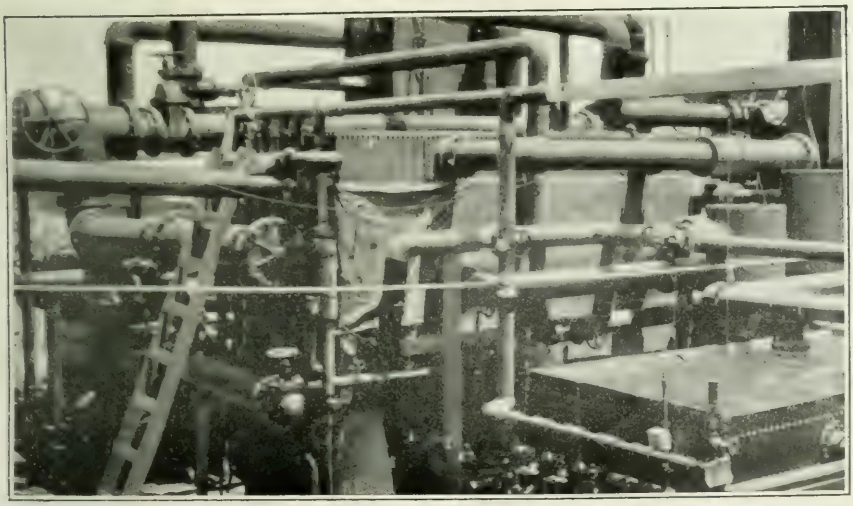


FIGURE 19.—Details of first type of Trumble separator, Fellows and Vernon plants.

partments for redistillation. Perforated steam pipes were also provided in each lower compartment to assist the action of the separators in fractionation. Figure 19 shows the details of this separator, and Plate XL, *B*, shows the separators in place.



A. FIRST TYPE OF PIPE RETORTS. VERNON TRUMBLE PLANT.



B. VIEW OF SEPARATORS AND DEPHLEGMATOR (IN BACKGROUND). VERNON TRUMBLE PLANT. NOTE WATER SEAL ON TOP OF THE SEPARATOR.

FORTY-EIGHT-INCH FIRST-RUN CONDENSERS.

The first-run vapor condensers each consisted of a horizontal steel cylinder 48 inches in diameter and 21 feet long with removable convex heads at the ends. Vertical tube sheets about 1 foot from either end formed a separate drum compartment at each end of the cylinder. Into these tube sheets one hundred and thirty-six 2-inch boiler tubes 18 feet long were expanded, and, by means of a horizontal partition in one drum, the liquid or vapor within the tubes was given two passes in its course through the apparatus. The liquid outside the tubes entered the cylinder at one end of the large compartment on the bottom and left at the other end on top in heat exchange with

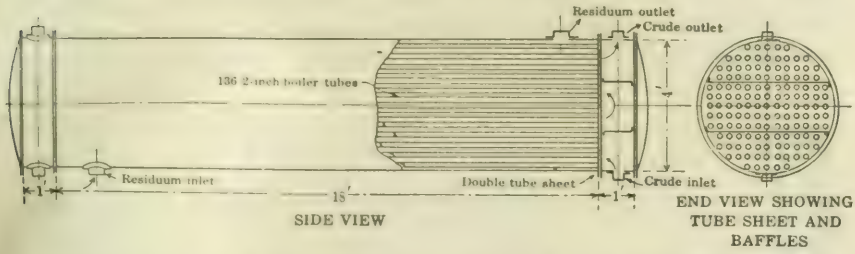


FIGURE 20.—Forty-eight-inch condenser and heat exchanger. Trumble plant at Vernon. Left, side view; right, end view showing tube sheet and baffles. Outside surface of tubes, 1,280.3 square feet; inside surface of tubes, 1,157.9 square feet.

the liquid in the tube. (See fig. 20.) Plate XXXVI, *B* (p. 90) and Plate XXXVIII (p. 96.) show the condensers and heat exchangers in place and also show the large dephlegmator.

FORTY-EIGHT-INCH HEAT EXCHANGERS.

The construction of the heat exchangers was the same as that of the 48-inch first-run condensers except that by means of additional baffles in the drum heads the fluid within the tubes made four passes in its course through the apparatus. The surrounding liquid as before was given one pass over the tubes.

Shortly after operation began in May, 1913, it became apparent that the heat exchanger surface was inadequate, and two additional exchangers were added.

THIRTY-INCH RERUN CONDENSERS.

The 30-inch rerun vapor condenser was of similar construction and contained fifty-two 2-inch boiler tubes 18 feet long expanded into the tube sheets. Liquids within the pipes made two passes through the apparatus, and those around the pipes made one (see fig. 21).

JACKETED LINE COOLERS.

The jacketed line distillate coolers consisted of several lengths of 4-inch or 6-inch pipe within an equal length of larger pipe. A stuffing box at the ends of the larger pipe permitted the free expansion or contraction of both pipes. The distillate to be cooled flowed within the smaller pipe countercurrent to the cooling liquid in the annular space between the pipes.

SECOND TYPE OF HEATER.

Early operation of the plant developed the fact that the heating surface in the heaters was insufficient, stack temperatures as high as 1,200° F. (648.9° C.) being recorded. Additional 4-inch pipes were therefore placed above the large pipes in one battery and connected in series by return bends to form a continuous upward course for the

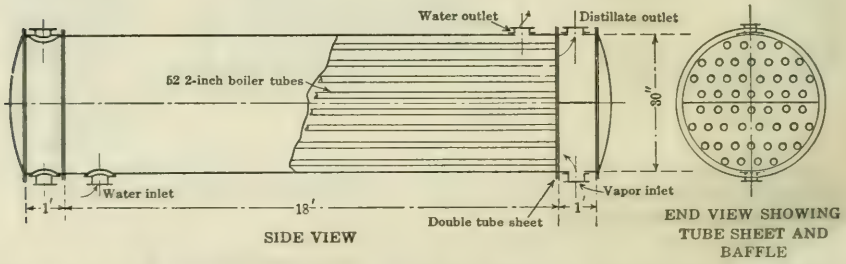


FIGURE 21.—Thirty-inch rerun condensers, Trumble plant at Vernon. Left, side view; right, end view showing tube sheet and baffle. Outside surface of tubes, 489.5 square feet; inside surface of tubes, 442.7 square feet.

oil back and forth over the furnace, which discharged into the top of the evaporator. A marked improvement was noted after this change.

Subsequently the company replaced the large pipes in the other battery with a continuous 4-inch coil constructed as follows:

Nine horizontal rows of six 4-inch lapwelded pipes were connected together by 4-inch flanged return bends at one end, and 4-inch screwed return bends at the other, permitting the ready replacement of any tube damaged in operation. The coil thus connected formed a continuous path for the oil entering at the bottom row and flowing back and forth and upwards through each row to the top of the evaporator. These rows of pipe were supported by a steel frame adjacent to the inner face of the heater brickwork and were entirely within the furnace except for the return bends. The combustion chamber was directly below the bottom row of pipes and the gases were given two passes over the pipes on their way to the space around the evaporator. The baffle walls in this furnace were arranged to force the combustion gases over the top four rows of pipes in their

first pass, and then downwards over the remaining pipes, the gases leaving the heater at the bottom. A flow roughly countercurrent to that of the oil under fire was thus attained (see fig. 22). The vent pipes previously mentioned were not used on this type of heater.

DEPHLEGMATOR.

A large rectangular dephlegmator (fig. 23) was also added to each battery for removing the heavy distillates from the first-run vapors. It consisted of a large steel box 4 by 4 feet by 16 feet high. Within the box were three rectangular vapor chambers about 3 feet 6 inches by 4 feet by 1 foot deep, and over each vapor chamber a similar water compartment about half their depth. One horizontal baffle was placed in the center of each vapor chamber to force vapors

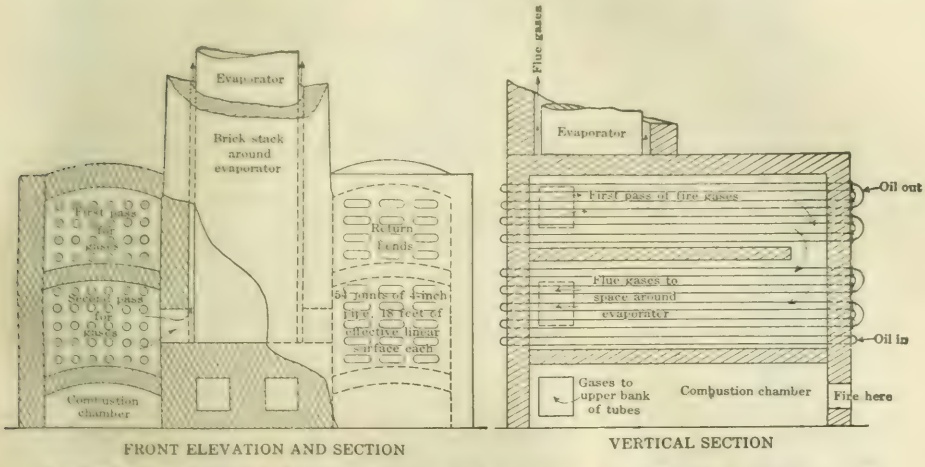


FIGURE 22.—Pipe retort and setting, Trumble plant at Vernon. Has 108 joints of 4-inch pipe with effective length of 1,944 feet. Outside heating surface, 2,292.4 square feet; inside heating surface, 2,050.6 square feet.

against the sides. The interior vapor chambers were interconnected by means of a 12-inch pipe outside the box, and the top vapor chamber was connected to the interior of the dephlegmator near the bottom by a similar pipe. Vapors entered the lowest vapor chamber, and passed through each to the bottom of the dephlegmator, discharging into the space surrounding the interior boxes; thence passing upward they encountered the cooling surfaces of the water compartments, dropping their heaviest fractions as condensate on the hot vapor chamber surfaces where parts were reevaporated. The heaviest fractions eventually reached the bottom of the apparatus and the light vapors were removed at the top. A perforated steam coil in the bottom of the dephlegmator permitted the use of direct steam as required (see fig. 23).

OPERATION.

The plant handles an oil with an average gravity of 22° B. (specific gravity, 0.922), containing about 0.5 per cent water, producing a fuel residue of 16° to 17° B. (specific gravity, 0.959 to 0.953), a No. 1 distillate of 58° B. (specific gravity, 0.747), a No. 2 distillate of 45° B. (specific gravity, 0.801), and a slop distillate of about 35 °B. (specific gravity, 0.848). When the plant is operated at normal capacity about a 15 per cent fraction at 500° F. can be removed in 24 hours from 12,000 barrels of dry oil of the quality mentioned.

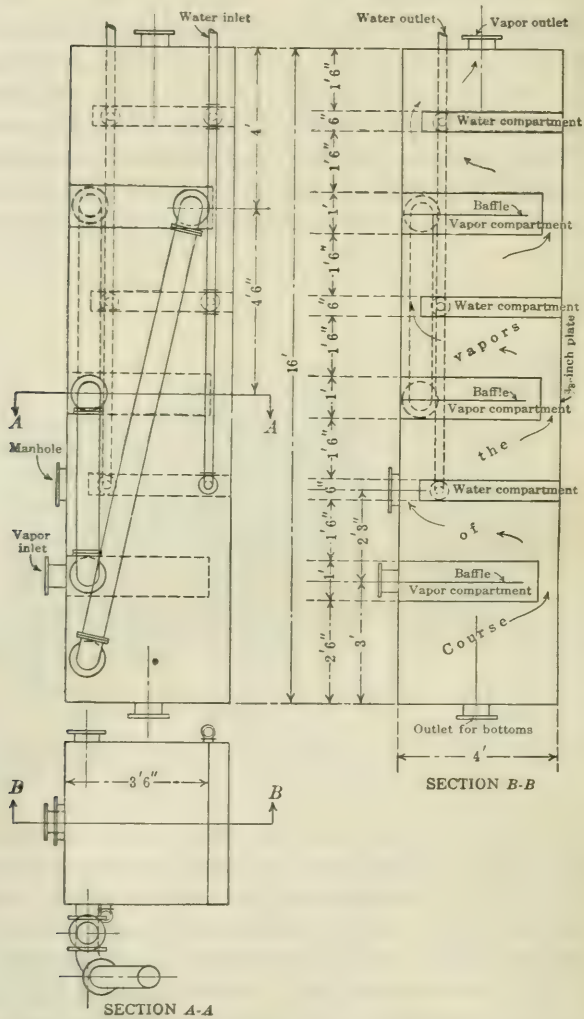


FIGURE 23.—Sections of rectangular dephlegmator, Trumble plant at Vernon.

The course of the oil and vapors through one battery of the plant is as follows:

The crude entering the plant is pumped through the tubes of the heat exchangers in series, being heated by the outgoing hot residuum, thence passes through the right and left heater pipes upward to the tee, 4 by 4 by 6 inches, entering the top of the evaporator. By means of the baffles the entering crude is continuously diverted in a thin film against the shell, and is heated by the outgoing flue gases.

The vapors evolved pass through the perforations in the vertical take-off line and thence through the heating pipes of separator 1

to the bottom vapor chamber of the dephlegmator. A by-pass provided permits sending a part of the vapors directly to the dephlegmator. The heavy distillate fraction condenses in this apparatus, and the lighter vapors pass through the tube of the 48-inch first-run vapor condensers in series, and are condensed by the water surrounding the tubes. The condensate returns to the liquid chamber of separator 1, being reevaporated by the heat of the vapors leaving the evaporator. Two vapors are evolved in separator 1, and the bottom distillate passes to separator 2.

The first top of separator 1 from vapor compartment 1 passes through the tubes of a 30-inch water condenser, and thence as condensate through a water-jacketed line cooler to storage. The second top of separator 1 also passes through a 30-inch condenser and jacketed line to storage.

The bottoms of separator 1 enter the liquid compartment of separator 2, and are reevaporated by the heat of the outgoing residuum, which passes through the tubes before entering the heat exchangers. A by-pass permits a part of the residuum to enter the heat exchangers directly, thus controlling the action of the separator. The bottoms of separator 2 combine with the bottoms from the dephlegmator, and, being cooled in a 30-inch condenser, pass to storage. The residuum leaving the evaporator passes through separator 2, thence in series through the heat exchangers, making one pass over the tubes containing the ingoing crude, and thence to storage tanks.

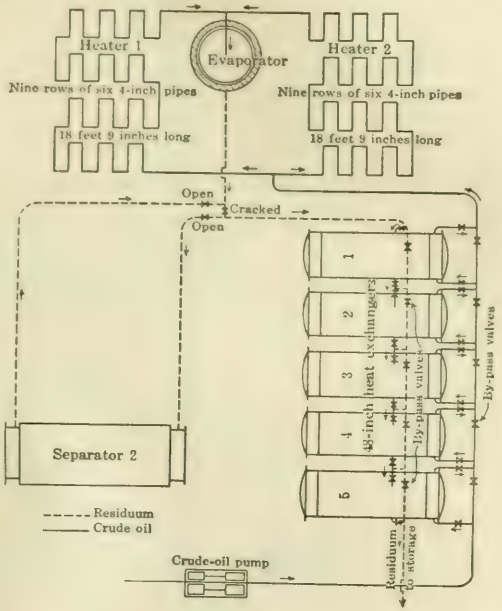


FIGURE 24.—Crude-oil and residuum flow sheet, Trumble plant at Vernon. .....residuum. ——crude oil.

The flow charts comprising figures 24 and 25 indicate the operation of the plant.

The products made and the fuel consumption for a four days' run with the average plant temperatures are shown in Table 21.

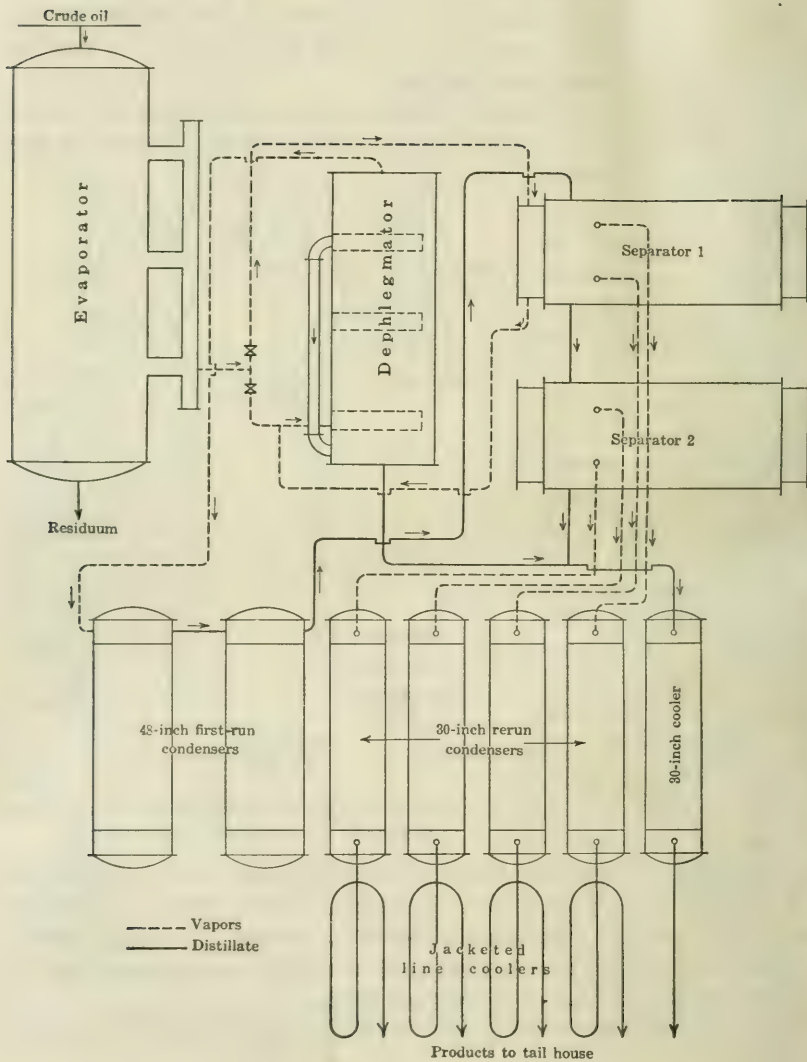


FIGURE 25.—Vapor and distillate flow sheet, Trumble plant at Vernon. .....vapor. ——distillate.

TABLE 21.—*Products and fuel consumption at the Vernon refinery.*

Date.	Crude run.	Gravity at 60° F.		Mud and base sediment.	No. 1 distillate.			No. 2 distillate.			Total distillates.	Fuel consumption.		Total.
		°F.	°C.		Per cent.	Gravity. °B.	Gravity. Specific gravity.	Per cent.	Gravity. °B.	Gravity. Specific gravity.		Retorts.	Boilers.	
1914.	*Barrels.*			*Per cent.*							*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
July 4	9,358	19.2	0.938	0.8	0.86	58.0	0.747	6.7	44.5	0.804	8.26	0.86	0.38	1.24
5	9,433	20.1	.933	.9	.86	58.0	.747	7.01	44.5	.804	8.77	.74	.42	1.16
6	9,253	19.5	.937	1.0	.86	58.0	.747	6.51	45.0	.801	8.37	.85	.35	1.20
7	9,952	19.7	.935	.7	.83	58.2	.746	6.25	45.0	.801	7.78	.86	.38	1.24
8	9,163	20.8	.929	.6	1.24	58.4	.745	13.4	43.5	.808	14.98	.95	.37	1.32
Average 4 to 8	9,431.5	19.8	.935	.8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

Temperature data.

Crude retorts.		Entering heat exchanger.		Crude retorts.		Leaving heat exchanger.		Residuum from heat exchanger.	
°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.
260	126.6	80	26.6	450	232.2	260	126.6	190	87.7

LABORATORY DISTILLATIONS.

CHARACTER OF PRODUCTS.

The results of several laboratory distillations made by the refinery chemist are shown below. These define the character of the oil run and the products made. Distillations 1 and 2 were from crude from the storage tank; distillation 3 was from combined tops. Distillation 4 was from a sample of the No. 1 distillate, and showed these products to contain 82 per cent of 61° B. gasoline (specific gravity, 0.735), having end points of 96° F. (35.6° C.) to 256° F. (124.4° C.).

Results of laboratory distillations of oil run in Trumble plant at Vernon.

DISTILLATION 1, CRUDE FROM STORAGE TANK.

Product made.	Per cent.	Temperature.		Gravity at 60° F. (15.6° C.)	
		°F.	°C.	°B.	Specific gravity.
Tops	20.0	147 to 500	63.9 to 260	40.3	.823
Residuum	78.6	.....	.....	14.8	.967
Water	1.4	.....	.....	.....	.....

DISTILLATION 2, CRUDE FROM STORAGE TANK.

Tops	20.0	150 to 503	65.6 to 261.6	40.6	.822
Residuum	78.6	.....	.....	14.3	.970
Water	1.4	.....	.....	.....	.....

DISTILLATION, 3 COMBINED TOPS.

Fraction.	Per cent over.	Temperature.		Gravity at 60° F. (15.6° C.)	
		°F.	°C.	°B.	Specific gravity.
1	2.0	97 to 250	36.1 to 121.1	58.5	.745
2	2.0	250 to 258	121.1 to 125.6	55.1	.758
3	2.0	258 to 262	125.6 to 127.8	54.0	.763
4	2.0	262 to 267	127.8 to 130.6	53.0	.767
5	2.0	267 to 270	130.6 to 132.2	52.2	.770
6	2.0	270 to 276	132.2 to 135.6	51.5	.773
7	2.0	276 to 280	135.6 to 137.8	50.9	.775
8	2.0	280 to 283	137.8 to 139.4	50.2	.778
9	2.0	283 to 289	139.4 to 142.8	49.6	.781
10	2.0	289 to 293	142.8 to 145.0	49.0	.784
11	2.0	293 to 298	145.0 to 147.8	48.6	.785
12	2.0	298 to 300	147.8 to 148.9	48.0	.788
13	2.0	300 to 306	148.9 to 152.2	47.6	.790
14	2.0	306 to 311	152.2 to 155.0	47.0	.792
15	2.0	311 to 315	155.0 to 157.2	46.5	.794
16	2.0	315 to 319	157.2 to 159.4	46.0	.797
17	2.0	319 to 322	159.4 to 161.1	45.5	.799
18	2.0	322 to 327	161.1 to 163.8	44.9	.802
19	2.0	327 to 330	163.8 to 165.5	44.4	.804
20	2.0	330 to 334	165.5 to 167.7	43.9	.807
21	2.0	334 to 341	167.7 to 171.6	43.3	.809
22	2.0	341 to 346	171.6 to 174.4	42.7	.812
23	2.0	346 to 351	174.4 to 177.2	42.2	.814
24	2.0	351 to 355	177.2 to 179.4	41.6	.817
25	2.0	355 to 360	179.4 to 182.2	41.0	.820
26	2.0	360 to 365	182.2 to 185.0	40.5	.822
27	2.0	365 to 367	185.0 to 186.1	40.1	.824
28	2.0	367 to 374	186.1 to 190.0	39.3	.828
29	2.0	374 to 384	190.0 to 195.5	38.5	.832
30	2.0	384 to 390	195.5 to 199.4	37.8	.835
31	2.0	390 to 394	199.4 to 201.1	37.3	.838

Results of laboratory distillations of oil run in Trumble plant at Vernon—Continued.

DISTILLATION, 3 COMBINED TOPS—Continued.

Fraction.	Per cent over.	Temperature.		Gravity at 60° F. (15.6° C.)	
		°F.	°C.	°B.	Specific gravity.
32	2.0	394 to 400	201.1 to 204.4	36.9	.840
33	2.0	400 to 406	204.4 to 207.7	36.1	.842
34	2.0	406 to 411	207.7 to 210.5	35.8	.845
35	2.0	411 to 417	210.5 to 213.8	35.2	.848
36	2.0	417 to 422	213.8 to 216.6	34.9	.849
37	2.0	422 to 426	216.6 to 218.8	34.6	.851
38	2.0	426 to 434	218.8 to 223.3	34.0	.854
39	2.0	434 to 441	223.3 to 227.2	33.4	.857
40	2.0	441 to 448	227.2 to 231.1	33.0	.859
41	2.0	448 to 454	231.1 to 234.4	32.4	.862
42	2.0	454 to 462	234.4 to 238.8	31.9	.865
43	2.0	462 to 470	238.8 to 243.3	31.4	.868
44	2.0	470 to 480	243.3 to 249.4	30.8	.871
45	2.0	480 to 494	249.4 to 256.6	30.0	.875
46	2.0	494 to 510	256.6 to 265.5	29.1	.880
47	2.0	510 to 525	265.5 to 273.8	28.0	.887
48	2.0	525 to 534	273.8 to 278.8	26.2	.897
Residue	1.5	.....	.....	.....	.....
Loss, gas etc.	2.5	.....	.....	.....	.....

SUMMARY OF DISTILLATION 3.

Fraction.	Per cent over.	Gravity at 60° F. (15.6° C.)		Per cent of calculated to crude oil.
		°B.	Specific gravity.	
1	2.0	58.5	0.745	0.4
2 to 11	20.0	51.1	.774	[a] 4.0
12 to 23	24.0	44.9	.802	4.8
24 to 29	12.0	40.0	.825	2.4
30 to 45	32.0	34.0	.854	6.4
46 to residue	[b] 7.5	.....	.....	1.5
Loss, gas, etc	2.5	.....	.....	.5

[a] Actual. [b] Per cent of fuel or smudge oil.

DISTILLATION 4, 61° B GASOLINE.

Fraction.	Per cent over.	Temperature.		Gravity at 60° F. (15.6° C.).	
		°F.	°C	°B.	Specific gravity.
1	2.0	96 to 156	35.6 to 68.8	75.5	0.683
2	2.0	156 to 164	68.8 to 73.3	74.2	.688
3	2.0	164 to 168	73.3 to 75.5	73.2	.691
4	2.0	168 to 172	75.5 to 77.7	72.0	.695
5	2.0	172 to 174	77.7 to 78.8	70.7	.700
6	2.0	174 to 176	78.8 to 80.0	69.9	.703
7	2.0	176 to 178	80.0 to 81.1	68.7	.707
8	2.0	178 to 182	81.1 to 83.3	67.8	.710
9	2.0	182 to 184	83.3 to 84.4	66.8	.713
10	2.0	184 to 186	84.4 to 85.5	66.1	.716
11	2.0	186 to 188	85.5 to 86.6	65.3	.719
12	2.0	188 to 190	86.6 to 87.7	64.4	.722
13	2.0	190 to 192	87.7 to 88.8	63.9	.724
14	2.0	192 to 194	88.8 to 90.0	63.3	.727
15	2.0	194 to 196	90.0 to 91.1	62.6	.729
16	2.0	196 to 198	91.1 to 92.2	62.0	.731
17	2.0	198 to 199	92.2 to 92.7	61.6	.733
18	2.0	199 to 200	92.7 to 93.3	61.0	.735
19	2.0	200 to 202	93.3 to 94.4	60.4	.737
20	2.0	202 to 203	94.4 to 95.0	60.1	.738
21	2.0	203 to 206	95.0 to 96.6	59.7	.740

Results of laboratory distillations of oil run in Trumble plant at Vernon—Continued.

DISTILLATION 4, 61° B GASOLINE—Continued.

Fraction.	Per cent over.	Temperature.		Gravity at 60° F. (15.6° C.).	
		°F.	°C.	°B.	Specific gravity.
22	2.0	206 to 208	96.6 to 97.7	59.1	.742
23	2.0	208 to 210	97.7 to 98.8	58.5	.745
24	2.0	210 to 212	98.8 to 100.0	58.1	.746
25	2.0	212 to 213	100.0 to 100.5	57.3	.747
26	2.0	213 to 215	100.5 to 101.6	57.5	.748
27	2.0	215 to 216	101.6 to 102.2	57.2	.749
28	2.0	216 to 218	102.2 to 103.3	56.8	.751
29	2.0	218 to 220	103.3 to 104.4	56.3	.753
30	2.0	220 to 223	104.4 to 106.1	56.0	.754
31	2.0	223 to 225	106.1 to 107.2	55.6	.756
32	2.0	225 to 228	107.2 to 108.8	55.4	.757
33	2.0	228 to 230	108.8 to 110.0	55.1	.758
34	2.0	230 to 232	110.0 to 111.1	54.8	.759
35	2.0	232 to 234	111.1 to 112.2	54.6	.760
36	2.0	234 to 236	112.2 to 113.3	54.3	.761
37	2.0	236 to 242	113.3 to 116.6	53.7	.764
38	2.0	242 to 244	116.6 to 117.7	53.5	.765
39	2.0	244 to 248	117.7 to 120.0	53.0	.767
40	2.0	248 to 252	120.0 to 122.2	52.5	.769
41	2.0	252 to 256	122.2 to 124.4	52.0	.771
42	2.0	256 to 260	124.4 to 126.6	51.4	.773
43	2.0	260 to 268	126.6 to 131.1	51.2	.774
44	2.0	268 to 278	131.1 to 136.6	50.5	.777
45	2.0	278 to 286	136.6 to 141.1	48.8	.785
46	2.0	286 to 298	141.1 to 147.7	47.7	.789
47	2.0	298 to 313	147.7 to 156.1	45.9	.797
Residue	2.8			40.8	.821
Loss, gas, etc	3.2				
Total, or average	82.0			61.0	.735
Average, as determined by weighing				60.4	.737

THEORETICAL FUEL CONSUMPTION.

The summary of the results of distillation 3 (p. 105) shows that the theoretical amount of heat required to remove a 16 per cent cut from 1 pound of the oil shown in samples 1 and 2 (distillates 1 and 2, p. 104) would be as follows, where the heat recovered in the exchangers is considered and no heat loss in the apparatus regarded:

Summary of sample 3.

[Gravity, 22° B. (0.922).]

Boiling point.		Specific gravity of fraction.	Per cent over.		Specific gravity of fraction.	Per cent of residue.	
			By volume.	By weight.		By volume.	By weight.
°F.	°C.						
100 to 250	37.8 to 121.1	0.745	0.4	0.326	0.922	98.2	98.16
250 to 300	121.1 to 148.8	.774	4.4	3.70	.928	93.8	94.46
300 to 350	148.8 to 176.6	.802	4.4	3.82	.935	89.4	90.64
350 to 400	176.6 to 204.4	.825	3.6	3.22	.940	85.8	87.42
400 to 450	204.4 to 232.2	.850	3.4	3.14	.945	82.4	84.28
Tops			16.2				
Water			1.4	1.51	.920	98.6	98.49

	B. t. u.
Specific heat of the crude (average value)	0.45
Latent heat of distillate (average value)	125.00
Specific heat of the vapors (average value)	.50
Specific heat of saturated steam	.48

Heat theoretically required to remove 16 per cent cut

				B. t. u.
To heat 0.982 pound of oil 250° to 300° F. (121.1° to 148.8° C.)	0.982	(250–300) ×	0.45 =	22.10
To evaporate 0.037 pound of vapors	.037		×125 =	4.62
To superheat 0.043 pound of vapors 250° to 300° F. (121.1° to 148.8° C.)	.043	(250–300) ×	0.5 =	1.15
To heat 0.945 pound of oil 300° to 350° F. (148.8° to 176.6° C.)	.945	(250–300) ×	0.45 =	21.30
To evaporate 0.0382 pound of vapors	.0382		×125 =	4.78
To superheat 0.081 pound of vapors 300° to 350° F. (148.8° to 176.6° C.)	.081	(300–350) ×	0.5 =	2.01
To heat 0.906 pound of oil 350° to 400° F. (176.6° to 204.4° C.)	.906	(350–400) ×	0.45 =	20.40
To evaporate 0.032 pound of vapors	.032		×125 =	4.00
To superheat 0.113 pound of vapors 350° to 400° F. (176.6° to 204.4° C.)	.113	(350–400) ×	0.5 =	2.83
To heat 0.874 pound of oil 400° to 450° F. (204.4° to 232.2° C.)	.874	(400–450) ×	0.45 =	19.65
To evaporate 0.031 pound of vapors	.031		×125 =	3.88
To superheat 0.144 pound of vapors 400° to 450° F. (204.4° to 232.2° C.)	.144	(400–450) ×	0.5 =	3.60
To superheat 0.0151 pound of steam 250° to 450° F. (121.1° to 232.2° C.)	.015	(250–450) ×	0.48 =	1.48
Total heat required to top 1 pound of 18.8° B. (specific gravity, 0.941) oil at 100 per cent efficiency				111.80
Total heat required to top 1 barrel of 18.8° B. (specific gravity, 0.941) oil at 100 per cent efficiency would be 330 pounds × 111.80 B. t. u.				[a] 36894.00

OVER-ALL EFFICIENCY OF THE TOPPING PLANT.

The average fuel consumption on the retort is 0.9 per cent of the crude run, or 0.009 barrel of fuel oil to 1 barrel of oil topped, which, with 15° B. fuel oil, is 56675.7 British thermal units, or 14283.1 calories.

The over-all efficiency of the battery of retorts is, therefore,

$$\frac{36894.0 \text{ B.t.u.}}{56675.7 \text{ B.t.u.}} = \frac{9301.0 \text{ calories}}{14283.1 \text{ calories}} = 65.3 \text{ per cent.}$$

EFFICIENCY OF HEAT EXCHANGERS.

The rate of heat transmission, per hour per square foot per degree of mean temperature difference, in the heat exchangers may be approximated from the plant temperatures previously given.

[a] 9,301.0 calories.

TABLE 22.—*Record of heat exchangers, Vernon refinery.*

Date.	Crude passing per hour.	Gravity per barrel.		Weight per barrel.	Temperature of crude.				Residuum passing per hour.	Gravity per barrel.	
					Ingoing.		Outgoing.				
		° B.	Specific gravity.		° F.	° C.	° F.	° C.		° B.	Specific gravity.
	Barrels.			*Pounds.*					*Barrels.*		
July 4–8, 1914	392.9	19.8	.935	327.09	80	26.6	260	126.6	.....	.....	.....
Oct. 1, 1914	287.2	19.2	.938	329.0	80	26.6	262	127.7	.....	16.3	.957

Date.	Weight per barrel.	Temperature of residuum.				Heating surface.	θ_m.		Heat transmitted per square foot, per hour, per degree of mean temperature difference.	Heat seemingly transmitted per square foot, per hour, per degree of mean temperature difference.
		Ingoing.		Outgoing.						
		° F.	° C.	° F.	° C.		° F.	° C.		
	Pounds.					*Square feet.*				
July 4–8, 1914	.....	450	232.2	190	87.7	6,094.50	147.5	64.1	11.6	.....
Oct. 1, 1914	335	440	226.6	198	92.2	6,094.50	145.1	62.8	8.8	10.8

This transfer rate compares favorably with the rates of other apparatus having the same function, and the exchanger has the advantage of a construction that permits repairs to be easily made. Attention is called to the increased rate of transfer developed when the fluids were passing at higher velocities. (Table 22.)

RECORD OF PLANT PERFORMANCE.

Following is a record of three months' performance of the entire plant, with a complete statement of operating expenses.

TABLE 23.—*Operating costs of the Vernon topping plant, November and December, 1913, and January, 1914.*

[Total oil run, 915,617 barrels.]

Power-plant operating expense:		
Material	$251.15	
Labor	1,019.07	
		$1,270.22
Fuel to entire refinery:		
14,153 barrels of 20° B. oil, at 56¾ cents a barrel	8,018.71	
		8,018.71
Power-plant maintenance:		
Material	194.03	
Labor	152.80	
		346.83
Refinery-apparatus operating expense:		
Material	64.75	
Labor	1,350.53	
		1,415.28
Refinery-apparatus maintenance:		
Material	645.66	
Labor	916.53	
		1,562.19
Trumble royalty on patent rights		13,267.72
Total expense		25,880.95
Actual operating expense per barrel of crude oil run, cents		$\frac{25,880.95}{915,617}=2.82$
General maintenance:		
Material	$1,281.82	
Labor	2,318.59	
		$3,600.41
Actual maintenance expense per barrel of crude oil run, cents		$\frac{3,600.41}{915,617}=0.39$
Total operating cost per barrel of crude oil run, cents		3.21
Total fuel used per barrel of crude run:		
Burned under retorts, per cent		0.90
Burned under boilers, per cent		0.64
Boiler equipment		Two 150-horsepower Heine boilers.
Boiler pressure		140-pound gage.
Hot-well temperature		180° F.

COST OF PLANT.

The plant as originally constructed cost approximately $85,000, including tanks, etc., as follows:

Original cost of plant.

Two 27,000-barrel residuum tanks	$13,000
One 15,000-barrel slop distillate tank	2,200
Six 1,000-barrel receiving tanks (water-sealed)	6,000
Total	21,200
Evaporators, separators, heat exchanger condenser, etc., including all apparatus built in the shop	24,000
Piping and fittings	18,000
Heaters and brickwork	6,000
Excavation, erecting, labor, and foundations	15,800
Total	85,000

These figures, excluding tankage, represent a cost of $5.60 per barrel of capacity, a cost considerably lower than the cost of the conventional plants previously described.

The plant had been operating continuously and successfully since its completion. Several improvements suggested by operation have been incorporated in later installations and are subsequently discussed.

COALINGA PLANT.

A small Trumble plant constructed by a producing company at Coalinga, Cal., embodied all the improvements developed by operation of previous installations. Construction began in May, 1915, and was completed in December of the same year.

The company shipped its production by pipe line to a large refinery on San Pablo Bay, but as the local market for distillates and fuel oils assumed greater proportions this plant was projected. Its purpose was therefore to produce sufficient quantities of distillates and fuel oil to supply the local demands. Any surplus residuum was then pumped with the remainder of the production to the large refinery to be further reduced or sold as a fuel oil.

DETAILED DESCRIPTION OF APPARATUS.

HEATERS.

One battery of two heaters discharging into a single evaporator was constructed. The heaters are each composed of six horizontal rows of eight 4-inch lapwelded pipes, 18 feet 9 inches long, laid parallel to each other, and connected together by flanged return bends on one end and screwed on the other end. The bottom row is placed 30 inches above the furnace floor, subsequent rows being each in turn

1 foot higher than the one preceding. A steel frame adjacent to the inner face of the heater brickwork supports these pipes independent of the heater walls and permits them to freely move longitudinally under temperature stresses. The heater brickwork completely in-

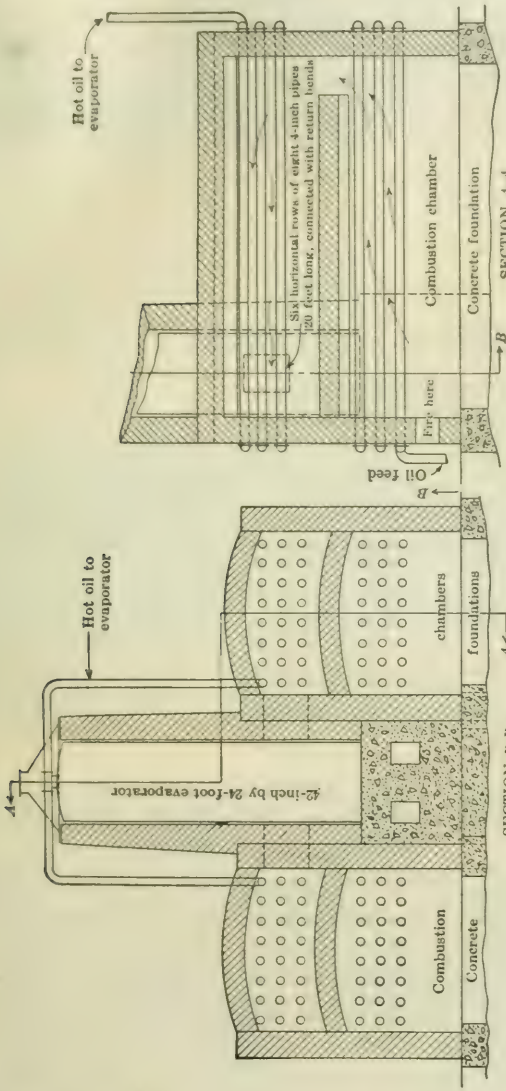


FIGURE 26.—Pipe retorts and settings, Trumble plant at Coalinga. Has 96 joints of 4-inch pipe with total effective length of 1,728 feet; outside heating surface, 2,037.9 square feet; inside, 1,822.7.

closes the pipe within the furnace except for the return bends. The two lowest rows are in contact with the fire, and the others are heated by escaping flue gases. The heaters are inclosed on top by brick arches, and the entire interior lined with fire brick. (See fig. 26.)

EVAPORATOR.

The evaporator is 42 inches in diameter and 24 feet high, being similar to those previously described, and heated by the flue gases leaving the heaters. Crude enters the lowest coil of the right and left heaters nearest the evaporator, travels backward, forward, and upward through each row of pipes, and thence through 4-inch pipes to the tee, 4 by 4 by 6 inches, at the top of the evaporator.

HEAT EXCHANGERS.

Two 36-inch diameter heat exchangers are provided similar in construction to those previously described. Ninety-five 2-inch boiler tubes 18 feet long are expanded into the double tube sheets at either end. The fluid within these tubes makes four passes in traveling

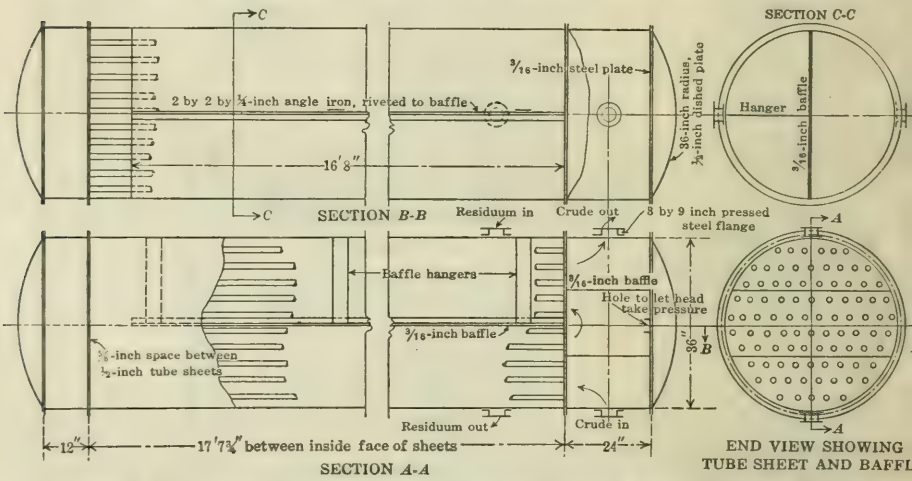


FIGURE 27.—Thirty-six-inch heat exchangers and condensers, Trumble plant at Coalinga. Has ninety-five 2-inch boiler tubes 18 feet long, rolled into double tube sheets. Outside surface of tubes, 858.7 square feet; inside surface, 776.7 square feet.

through the apparatus, and the fluid outside the tubes, by reason of a horizontal baffle in the large compartment, makes two passes.

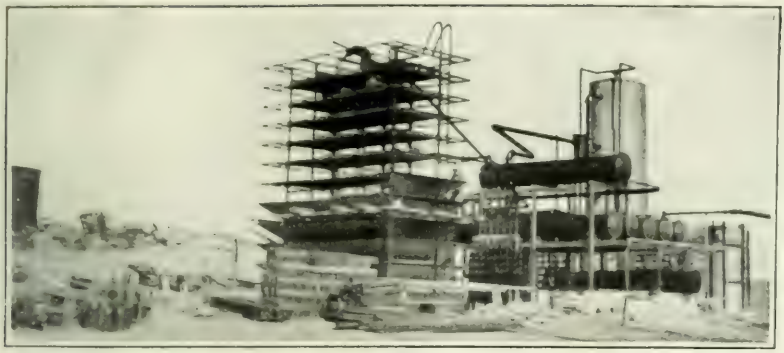
CONDENSERS.

The construction of the condenser for the first-run distillate is identical with that of the heat exchangers. Figure 27 shows these exchangers and condensers.

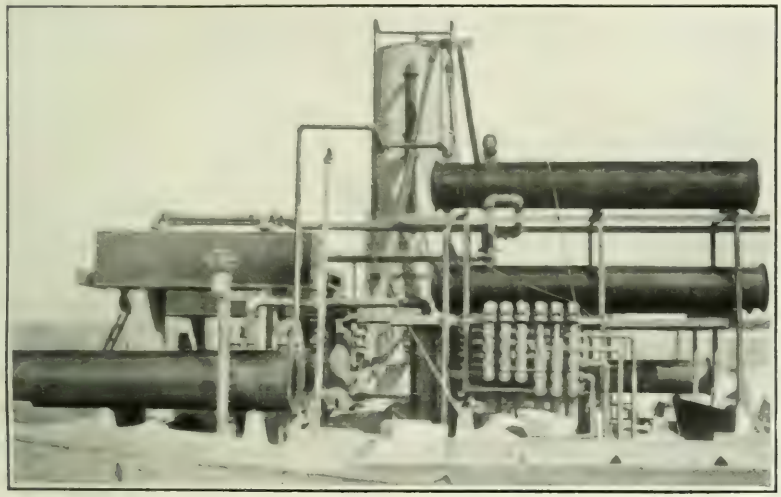
Six 30-inch water-cooled condensers handle the various products from the plant. They are similar to the heat exchangers and contain fifty-nine 2-inch boiler tubes 18 feet long expended into double tube sheets. The liquids or vapors make the same number of passes through these condensers as in the heat exchangers. The general assembly of these units and their position with respect to the remainder of the plant are shown in Plate XLI, *B*.

SEPARATORS.

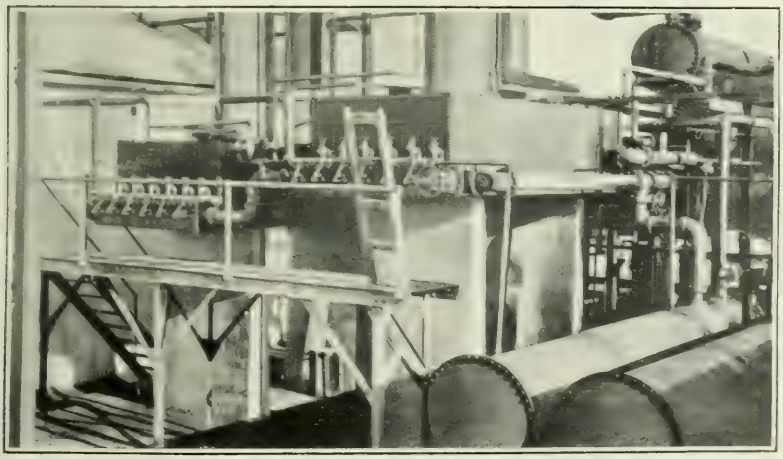
The constructions of the two separators used is somewhat different from that of the separators previously used. Each consists of a steel box 14 by 6 feet by 40 inches high, with the manifold at either end.



A. COALINGA TRUMBLE PLANT, DURING CONSTRUCTION.



B. VIEW OF CONDENSERS, HEAT EXCHANGERS, AND SEPARATORS. COALINGA TRUMBLE PLANT.



C. SEPARATORS SHOWING DEPHLEGMATORS AND HEAT EXCHANGERS IN FOREGROUND. COLINGA TRUMBLE PLANT.

The interior of the box is partitioned as before, but in each of the six lower compartments six 2-inch boiler tubes are expanded into the manifold heads. A perforated steam pipe above these pipes in each compartment furnishes additional heat as required, and also assists in carrying to the upper chambers the vapors evolved. Heavy

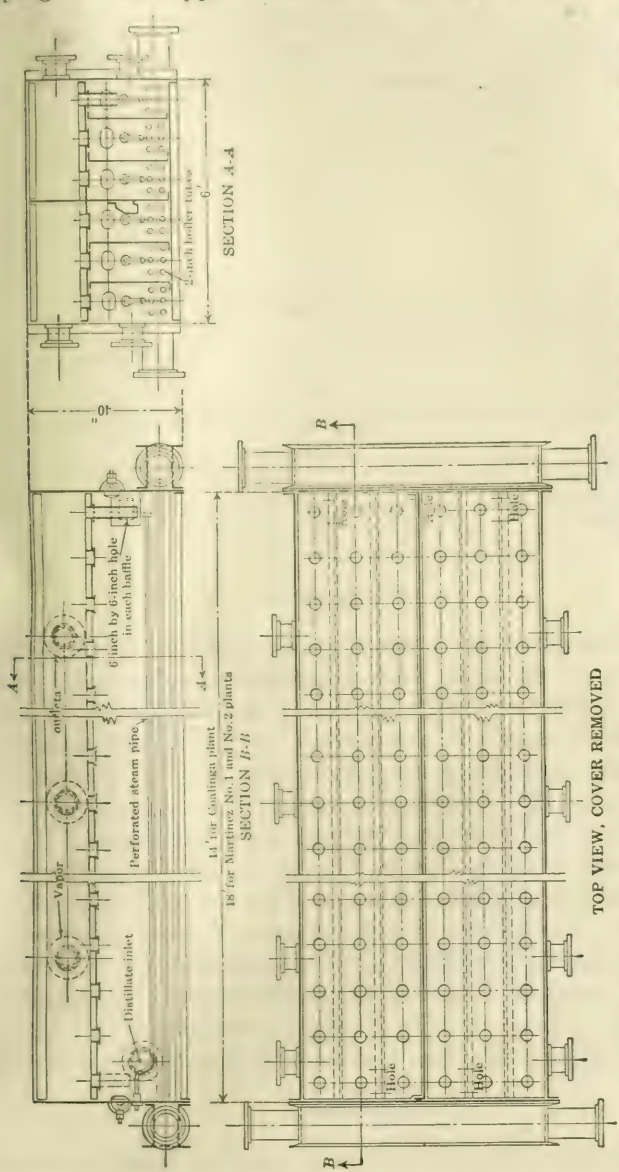


FIGURE 28.—Second type of Trumble separator, used in Coalinga and Martinez plants. 14-foot tubes used with Coalinga plant, external heating surface of one unit 257.74 square feet, internal, 233.24; 18-foot tubes used with Martinez plant, external surface, 331.4 feet; internal, 300.

vapors are condensed on the horizontal partition between the upper and lower compartments and retained as a thin film to cool additional heavy vapors. The overflow from this partition constantly returns to the lower compartments (see fig. 28). Square holes 6 by 6 inches

at alternate ends in the vertical walls of the lower compartments force the entering liquid back and forth across the pipes during fractionation. Supported upon each separator are two dephlegmators, each opening directly into a vapor chamber of the separator.

The flow chart (fig. 31) on page 117 shows these dephlegmators on one side of the separators, but Plates XLII and XLIII show their true positions. Plate XLI, *B*, shows the separators prior to the addition of the dephlegmators, and Plate XLI, *C*, shows a closer view after their installation.

Data on apparatus shown in Plate XLII.

No.	Part.	Size.	Number required.
1	Evaporator	3 feet 6 inches by 25 feet	1
2	Heat exchanger of 2-inch pipe 18 feet long.	3 feet by 7 feet 11 inches	2
3	Condenser of 2-inch pipe 18 feet long.	3 feet by 7 feet 11 inches	1
4	Separator	6 by 14 feet	2
5	Condenser of 2-inch pipe 18 feet long.	2 feet 6 inches by 4 feet 11 inches	6
6	Dewatering tanks	2 feet by 6 feet	3
7	Dephlegmator separators	2 feet 6 inches by 7 feet	4
8	Vapor column	6 by 8 by 12 inches	1
9	Oil separator	2 feet in diameter	1

DEPHLEGMATORS.

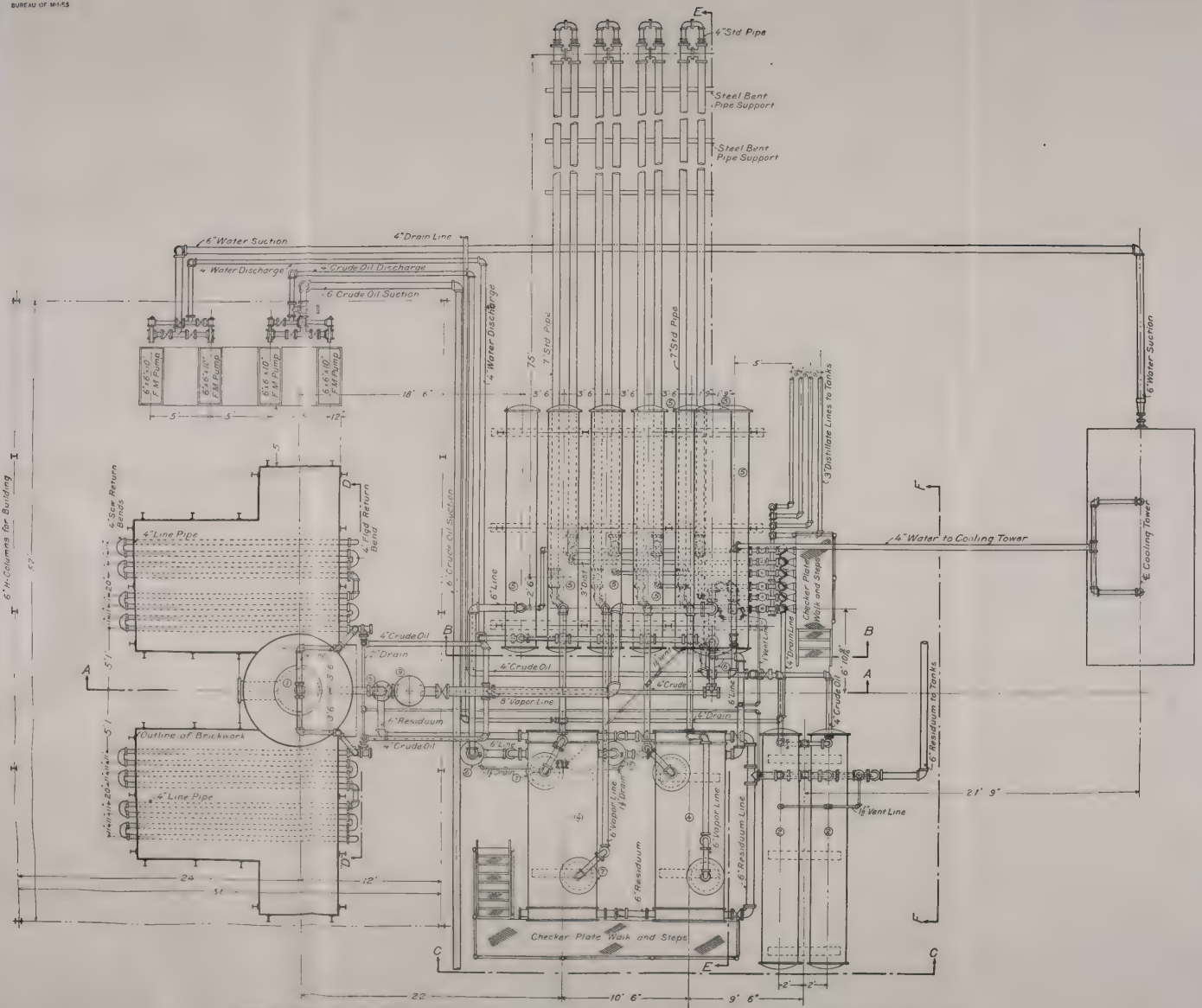
The dephlegmators are vertical cylindrical steel shells 30 inches in diameter by 7 feet high. Ten horizontal circular baffle plates are supported by four vertical rods within the apparatus. Five of the plates are fitted closely to the inside face of the shell, a circular hole in their center permitting the passage of vapors. Alternating with these are five plates of smaller diameter, the annular space between them and the shell permitting the passing of the vapors.

Vapors enter at the bottom and in traveling to the outlet at the top pass back and forth over the surfaces of the baffles. Heavy distillates condense on these plates and, by means of holes provided, finally return to the liquid compartment of the separator for refractionation.

A compartment at the top of the dephlegmator contains circulating cooling-water coils around which the vapors pass before leaving the apparatus. Figure 29 shows the construction of this dephlegmator.

OIL CATCHER.

An oil catcher is placed in the main vapor line from the evaporator. Its construction resembles that of a water trap in a steam line, and the vertical baffles furnish a tortuous path for the vapors passing through it. Heavy distillates, or oil mechanically carried by the



GENERAL ARRANGEMENT AND PIPING FOR TRUMBLE REFINING PLANT, COALINGA, CAL. FOR SECTIONS THROUGH *AA*, *BB*, *CC*, *DD*, *EE*, AND *FF* SEE PLATE XLIII.

d
s
p
i
t
t

p
c
r

c
a

Its
th
th

vapors, impinge upon these baffles and flowing down them collect at the bottom and are returned to the evaporator. (See fig. 30.)

JACKETED LINE COOLERS.

The jacketed line coolers are used to cool the distillates from the condensers before going to storage. Each consists of two runs of

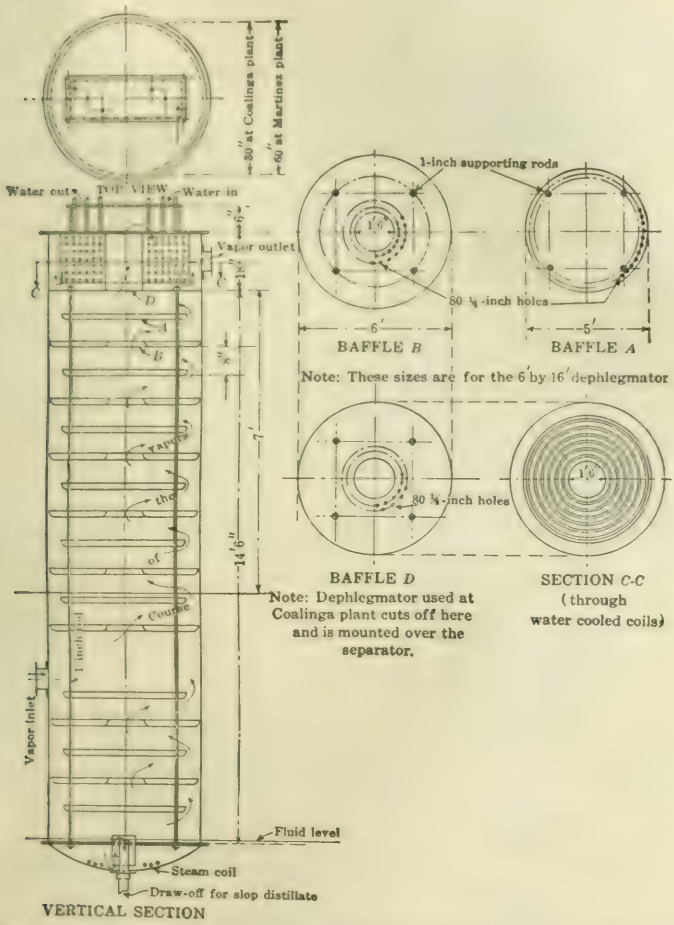


FIGURE 29.—No. 2 type of Trumble dephlegmator, used at Coalinga and Martinez plants. Area of baffle plates shown, 400 square feet, outside radiating surface, 378 square feet. Cooling surface of three concentric 1½-inch water coils—external surface, 256 square feet; internal surface, 217 square feet.

4-inch standard pipe 75 feet long connected at one end by flanged ells. A jacket of 7-inch standard pipe surrounds the 4-inch pipe, the two being connected at one end by flanged tees. The cooling medium flows within the jacket countercurrent to the outgoing distillate.

WATER TRAPS.

Water-separating traps are installed in the distillate lines, as shown on the flow sheet (fig. 31). Each consists of a hollow vertical cylinder 24 inches in diameter by 6 feet in height. The distillate enters at

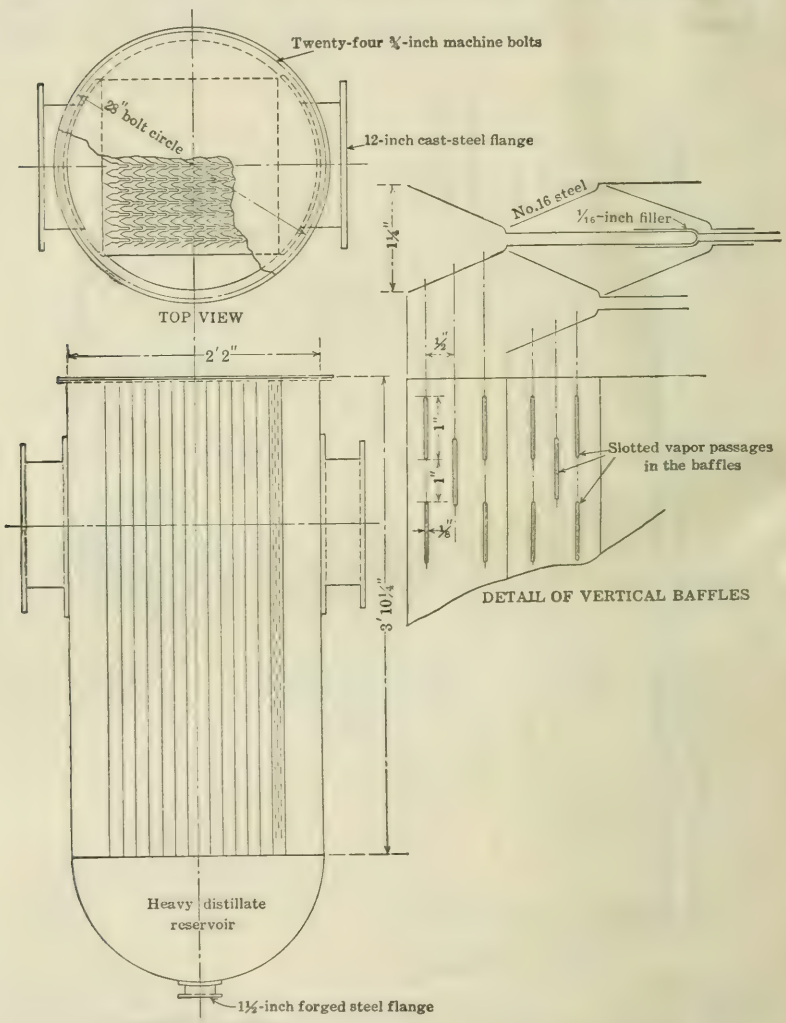
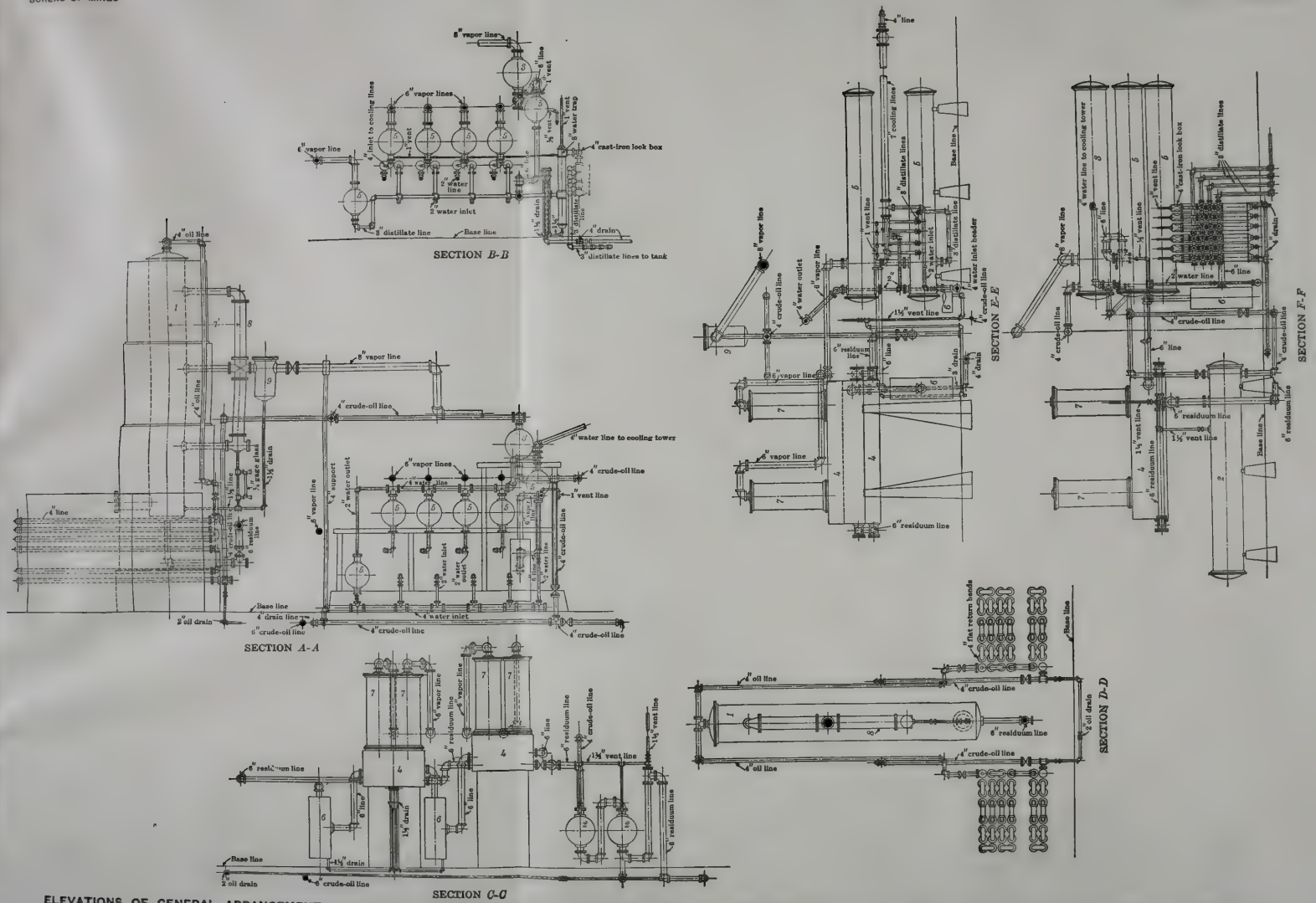


FIGURE 30.—Oil catcher in Trumble plants at Coalinga and Martinez.

one side and leaves at the top. By reason of the diminished velocity, the water settles at the bottom of the cylinder and is withdrawn by a 1½-inch drain line.



ELEVATIONS OF GENERAL ARRANGEMENT AND PIPING, TRUMBLE REFINING PLANT, COALINGA, CAL. FOR GENERAL PLAN SEE PLATE XLII. FOR LIST OF PARTS SEE PAGE 114.

COOLING TOWERS.

The water used in the dephlegmator, condensers, and jacketed lines is cooled by two cooling towers each 12 by 20 feet by 20 feet

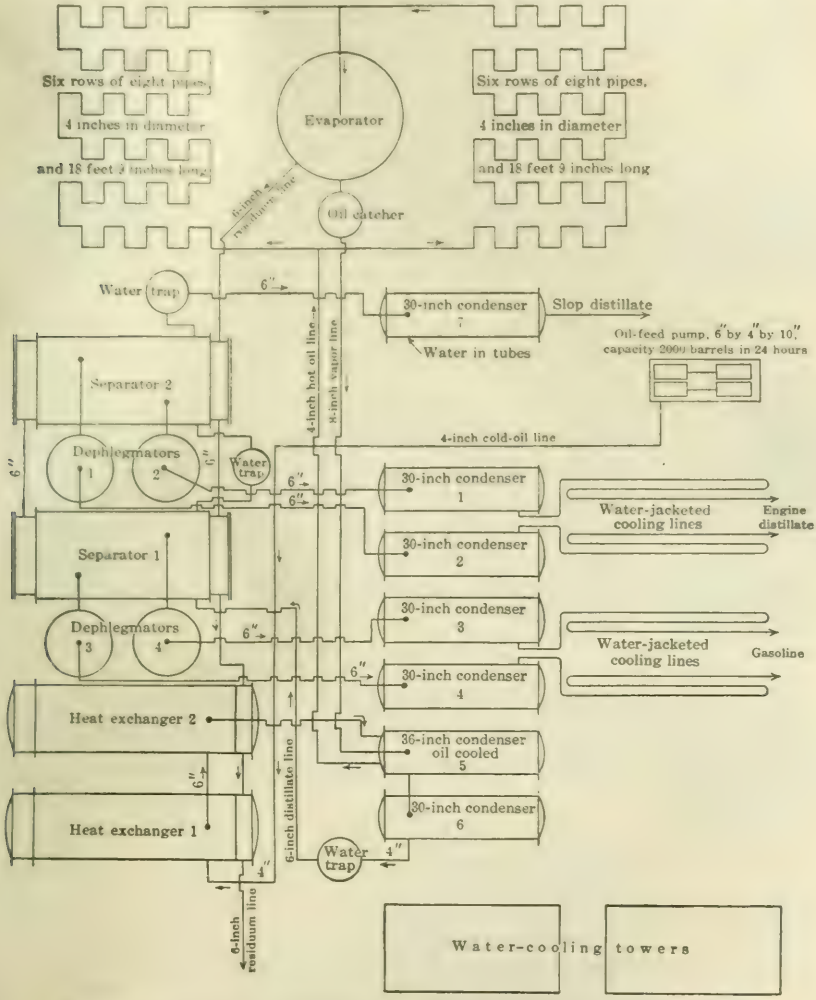


FIGURE 31.—Crude-oil, residuum, and distillate flow sheet, Trumble plant at Coalinga.

high. Originally one tower was used. Table 24 following gives a record of the plant temperatures before and after the addition of the second tower.

TABLE 24.—*Comparison of plant temperatures for months of July (to 18th) and August (to 29th), coolings, Trumble plant.*[a]

JULY, WITH ONLY ONE COOLING TOWER.

[Average crude treated daily, 1,468.29 barrels.]

Location.	Maximum temperature.				Minimum temperature.				Average temperature.			
	1 a. m.		1 p. m.		1 a. m.		1 p. m.		1 a. m.		1 p. m.	
	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.
Crude intake	92	33.3	92	33.3	82	27.7	82	27.7	86	30.0	88	31 1
Residuum	460	237.7	480	248.8	430	221.1	440	226.6	452	233.3	460	237.7
Plant, right	510	265.5	520	271.1	460	237.7	480	248 8	490	204.4	484	251.1
Plant, left	515	268.3	520	271.1	475	246.1	470	243.3	493	256.1	494	256.6
Water to tower 1	107	41.6	125	51.6	90	32.2	95	35.0	100	37.7	109	42.7
Water from tower 1	95	35.0	107	41.6	78	25.5	83	28.3	87	30.5	96	35.5
Evaporator	375	190.5	382	194.4	360	182.2	362	183.3	368	186.6	372	188.8

AUGUST, AFTER SECOND COOLING TOWER HAD BEEN BUILT.

[Average crude treated daily, 2,096.37 barrels.]

Crude intake	96	35.5	94	34.4	84	28.8	84	28.8	90	32.2	90	32.2
Residuum	440	226.6	450	232.2	420	215.5	415	212.7	428	220.0	432	222.2
Plant, right	480	248.8	520	271.1	450	232.2	450	232.2	470	243.3	477	247.2
Plant, left	490	204.4	500	260.0	460	237.7	450	232.2	472	224.4	477	247.2
Water to tower 1	104	40.0	110	43.3	89	31.6	86	30.0	97	36.1	101	38.3
Water to tower 2	100	37.7	100	37.7	82	27.7	74	23.3	88	31.1	91	32.7
Water from tower 1	90	32.2	95	35.0	78	25.5	74	23.3	83	28.3	88	31.1
Water from tower 2	90	32.2	85	24.4	70	21.1	62	16.6	75	23.8	78	25.5
Evaporator	370	187.7	372	188.8	358	181.1	360	182.2	364	184.4	365	185.5

[a] Before the second cooling towers were built about 17,000 barrels of water was pumped over the tower in 24 hours; now approximately 6,200 barrels is used in 24 hours, which is pumped by two Fairbanks-Morse duplex pumps, 6 by 6 by 10 inches.

BOILERS AND TANKS.

Two horizontal tubular boilers, one rated at 80 horsepower, the other at 60 horsepower, supply steam to the plant and operate the pumps required. Following is a list showing the number and kinds of tanks used:

List of tanks.

2 2,000-barrel crude tanks.
1 10,000-barrel residuum tank.
2 1,000-barrel residuum gage tanks.
2 150-barrel gasoline gage tanks.
2 150-barrel engine-distillate gage tanks.
4 150-barrel slop-distillate gage tanks.
1 1,000-barrel engine-distillate receiving tank.
1 1,000-barrel gasoline receiving tank.
1 1,000-barrel slop receiving tank.

OPERATION.

The crude is pumped by a Fairbanks-Morse duplex pump, 6 by 6 inches by 10 feet, from the supply tank to the bottom of the first heat exchanger, through the tubes and out at the top, thence through the second heat exchanger, being heated by the hot outgoing residuum flowing countercurrent to it around the tubes (see Pl. XLIII). From

the heat exchangers the partly heated oil enters the 36-inch first-run vapor condenser, flowing through the tubes in heat exchange with the vapors from the evaporator surrounding them. Then the oil flows to the heaters, dividing to the right and left heaters, and enters at the bottom coils adjacent to the evaporator, passing back and forth and upward through each coil. The oil from each heater enters the top of the evaporator through a tee, 4 by 4 by 6 inches, and flows in a thin film down the sides, guided by the conical baffles. The residue collecting in the bottom is drawn from the evaporator by a 6-inch line and is pumped in series through the tubes of each separator supplying the heat for reevaporating the distillates surrounding the tubes. Then it passes in series around the tubes of the heat exchangers, heating the incoming crude, and thence passes to storage.

The vapors separated from the hot oil in the evaporator pass through the oil catcher to the 36-inch first-run vapor condenser. Heavy distillates mechanically entrained in these vapors are caught and returned to the evaporator from the bottom of the oil catcher. Entering the large condenser around the tubes the vapors are condensed by the incoming crude, the condensate gravitating to condenser No. 6 to be cooled by the water circulating through the tubes.

From No. 6 condenser the condensate enters a water trap, dropping its water content, and passes to the liquid compartment of separator 1 for redistillation. In separator 1 it makes six passes over the tubes containing the outgoing residue from separator 2, and the lightest products evaporate and enter the two vapor chambers. The heavy fraction gravitates to separator 2, passing over the tubes containing the hot residuum from the evaporator, and an additional fraction is evaporated and enters the vapor chambers. The bottom distillate of separator 2 gravitates to a water trap and thence to a sealed 30-inch condenser, where it is cooled by the water within the tubes. Thence it enters the tank as slop distillate.

The first vapor from compartment 1 of separator 1 passes into the dephlegmator above, in which the heavier fractions are separated, and returns them as condensate to the separator for redistillation. The lightest vapors pass from the dephlegmator to condenser 4 around the tubes containing water, and thence into a jacketed line cooler as condensate, whence the condensate passes through a water trap to storage.

The second top of separator 1 and the first and second tops of separator 2 each receive like treatment before going to storage.

In normal operation the tops of separator 1 are condensed as gasoline and the tops of separator 2 as No. 1 distillate.

As shown in section FF of Plates XLII and XLIII (pp. 114 and 116), 4-inch cast-iron "look boxes" are provided on each distillate line from

the condensers for the inspection of the products before going to storage. One-inch vent pipes are provided for each box; also a 1½-inch vent from the heat exchangers and the 6-inch residuum standpipe, as shown in section CC of Plate XLI, relieve any uncondensed vapors and permit the operator to detect any foaming that occurs in running a very wet oil too rapidly through the plant. The plant operates continuously, two shifts of 12 hours each constituting a day's run. The operating force consists of 1 stillsman at $5 a day; 1 fireman at $3.50 a day; 1 pumpman at $3 a day; and 1 assistant chemist at $75 a month. This represents a total labor charge of $28 a day.

MISCELLANEOUS PLANT RECORDS.

The writer inspected this plant in November, 1916, and the additional records following were taken with the intention of determining an average rate of heat transmission in the different units. Accurate experiments for these determinations were impossible without special arrangements for metering the flow of the liquids involved, but the results following are given as being typical of the performance of the apparatus tested.

TABLE 25.—*Record of operation of Trumble plant at Coalinga during four months of 1910.*

Month.	Crude run.	Gravity of crude run.		Products made from crude.								Refining loss.		Number of days in operation.
				Gasoline.		Distillate.		Slop distillate.		Residuum.				
		°B.	Specific gravity.	Barrels.	Per cent.	Barrels.	Per cent.	Barrels.	Per cent.	Barrels.	Per cent.	Barrels.	Per cent.	
	Barrels.													
July	51,767	.....	.....	931.0	1.8	1,753.0	3.4	6,915.0	13.4	42,016.0	81.16	149.0	0.3	31
August	64,868	.....	.....	1,376.5	2.12	1,727.5	2.66	5,116.0	12.5	53,242.4	82.08	405.75	.63	31
September	61,980	21.5 to 23.0	0.925 to 0.916	1,475.0	2.38	1,845.0	2.98	8,281.0	13.36	50,055.0	80.76	323.0	.52	(a)
October	57,925	21.4 to 22.6	.925 to .918	1,619.3	2.8	1,681.1	2.9	9,179.1	15.85	45,126.5	77.9	319.0	.55	31

a 29 days, 22 hours.

TABLE 26.—*Results of laboratory and of refinery distillations, Trumble refinery at Coalinga.*

Laboratory distillations.								Refinery distillations.					
Gravity of crude.		Gasoline.			Distillate.			Gasoline.			Distillate.		
		Gravity.		Per cent of crude.	Gravity.		Per cent of crude.	Gravity.		Per cent of crude.	Gravity.		Per cent of crude.
°B.	Specific gravity.	°B.	Specific gravity.		°B.	Specific gravity.		°B.	Specific gravity.		°B.	Specific gravity.	
AUGUST, 1916.													
21.9	0.922	59.0	0.743	2.14	50.0	0.779	2.76	59.0	0.743	2.33	49.8	0.780	2.65
21.4	.925	59.0	.743	1.84	50.0	.779	2.76	59.3	.741	2.02	49.9	.780	2.40
21.4	.925	59.0	.743	2.09	50.0	.779	2.45	59.2	.742	2.00	49.6	.781	2.87
21.6	.924	59.0	.743	1.84	50.0	.779	2.80	59.2	.742	1.87	49.5	.781	2.61
21.7	.923	58.9	.743	1.94	50.0	.779	2.59	59.0	.743	2.16	49.5	.781	2.32
SEPTEMBER, 1916.													
21.8	0.923	59.0	0.743	2.58	50.0	0.779	2.25	59.4	0.741	2.47	49.9	0.780	2.80
22.1	.921	58.9	.743	2.58	50.0	.779	2.64	59.6	.740	2.53	49.8	.780	3.09
21.9	.922	59.0	.743	2.28	50.0	.779	2.60	59.5	.741	2.27	49.6	.781	2.86
22.0	.922	59.0	.743	2.32	50.0	.779	2.58	59.3	.741	2.44	50.0	.779	2.96
22.0	.922	59.0	.743	2.54	50.0	.779	2.70	59.2	.742	2.58	50.0	.779	3.35
22.3	.920	59.0	.743	2.63	50.0	.779	2.92	59.0	.743	2.76	49.8	.780	3.18
21.7	.924	59.0	.743	1.96	50.0	.779	2.25	59.0	.743	2.07	49.8	.780	2.73
21.5	.925	59.0	.743	2.12	50.0	.779	2.16	59.1	.742	2.00	50.0	.779	3.07
21.9	.922	59.0	.743	2.14	50.0	.779	2.76	59.0	.743	2.33	49.8	.780	2.66
OCTOBER, 1916.													
22.5	0.919	59.0	0.743	3.16	49.8	0.780	2.28	59.0	0.743	3.37	49.8	0.780	2.84
22.5	.919	58.7	.744	3.20	49.0	.784	2.10	59.5	.741	3.10	50.0	.779	3.28
22.3	.920	59.0	.743	3.15	50.0	.779	2.01	59.0	.743	3.05	50.0	.779	2.94
22.3	.920	59.0	.743	2.96	50.0	.779	2.26	59.6	.740	2.71	50.1	.779	3.08
22.3	.920	59.0	.743	2.65	50.0	.779	2.10	59.0	.743	3.31	49.9	.780	2.11
21.9	.922	59.0	.743	2.85	50.0	.779	2.43	59.3	.741	3.17	49.8	.780	2.51
22.2	.921	59.0	.743	2.60	50.0	.779	1.78	59.2	.742	2.31	49.8	.780	3.50
21.4	.925	59.0	.743	1.85	50.0	.779	2.71	59.4	.741	1.51	49.8	.780	3.26
22.0	.922	59.0	.743	2.06	50.0	.779	2.69	59.4	.741	2.04	50.0	.779	3.01

TABLE 27.—*Plant temperatures at Trumble plant, Coalinga.*

Location.	Maximum temperature.				Minimum temperature.				Average temperature.			
	1 p. m.		1 a. m.		1 p. m.		1 a. m.		1 p. m.		1 a. m.	
	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.
SEPTEMBER.												
Crude intake	92	33.3	92	33.3	76	24.4	78	25.5	86	30.0	86	30.0
Residuum	450	232.2	445	229.4	415	212.7	420	215.5	428	220.0	429	220.5
Plant, right	500	260.0	490	254.4	430	221.1	460	237.7	474	245.5	477	247.2
Plant, left	500	260.0	490	254.4	430	221.1	460	237.7	473	245.0	473	245.0
Water tower 1	105	40.5	105	40.5	93	33.8	84	28.8	100	37.7	95	35.0
Water tower 2	99	37.2	98	36.6	84	28.8	75	23.8	91	32.7	87	30.5
Water from tower 1	95	35.0	92	33.3	81	27.4	74	23.3	88	31.1	83	28.3
Water from tower 2	87	30.5	80	26.6	72	22.2	65	18.3	79	26.1	74	23.3
Evaporator	428	220.0	420	215.5	358	181.1	350	176.6	372	188.8	373	188.8
OCTOBER.												
Crude intake	84	28.8	78	25.5	64	17.7	68	20.0	72	22.2	72	22.2
Residuum	460	237.7	445	229.4	380	193.3	400	204.4	419	215.0	421	246.1
Plant, right	500	260.0	500	260.0	440	226.6	460	237.7	478	247.7	476	246.6
Plant, left	505	262.7	500	260.0	450	232.2	450	232.2	477	247.2	477	247.2
Water to tower 1	110	43.3	100	37.7	81	27.4	75	23.8	97	36.1	92	33.3
Water to tower 2	98	36.6	98	36.6	74	23.3	72	22.2	89	31.6	85	24.4
Water from tower 1	90	32.2	90	32.2	67	19.4	62	16.6	83	28.3	79	26.1
Water from tower 2	88	31.1	88	31.1	61	16.1	58	14.4	76	24.4	72	22.2
Evaporator	422	216.6	428	220.0	370	187.7	374	190.0	402	205.5	401	205.0

RECORD OF PLANT PERFORMANCE.

Table 25 shows the performance of the plant for four months of 1916, Table 26 the comparative results of laboratory and of plant distillations, and Table 27 a record of plant temperatures. During these several months representative samples were taken of the different products and Engler distillations were made. The results define the nature of these products and are given below.

Results of Engler distillation of products from Trumble plant at Coalinga in August, 1916.

GASOLINE.

[Quantity, 100 c. c.; gravity at 60° F. (15.6° C.), 59.0° B. (0.743); color, water white; odor, good; initial boiling point, 125.6° F. (52° C.).]

Boiling point of fraction.		Per cent vaporized.
°F.	°C.	
125.6 to 167	52.0 to 75.0	4.7
167.0 to 212	75.0 to 100.0	26.3
212.0 to 257	100.0 to 125.0	41.3
257 to 302	125.0 to 150.0	16.7
302.0 to 347	150.0 to 175.0	5.1
Final boiling point: 363.2	184.0	1.7
Residue		1.4
Loss		2.8

DISTILLATE.

[Quantity, 100 c. c.; gravity at 60° F. (15.6° C.), 50.1° B. (0.779); color, water white; odor, good; initial boiling point, 203° F. (95° C.).]

Boiling point of fraction.		Per cent vaporized.
°F.	°C.	
203 to 212	95 to 100	Trace.
212 to 257	100 to 125	22.6
257 to 302	125 to 150	52.7
302 to 347	150 to 175	17.9
Final boiling point: 388.4	198	4.2
Residue		1.6
Loss		1.0

SLOP DISTILLATE.

Gravity, 36.3° B. (0.842).
Initial boiling point, 287.6° F. (142° C.).
Gravity of first 17 c. c. out of 2000 c. c. was 44.9° B. (0.802).
Flash point, 120° F. (48.8° C.), by open-cup test.

Test of products made in August, 1916.

RESIDUUM.

Gravity, 18.2° B. (0.945).
Flash point, 222.8° F. (106.0° C.) in Bureau of Mines cup.
Flowing point, below 4° F.
Engler viscosity, 5.83 at 122° F. (50.0° C.).

Test of products made in August, 1916—Continued.

GASOLINE.

[Quantity, 100 c. c.; gravity at 60° F. (15.6° C.), 58.7° B. (0.744); color, water white; initial boiling point, 120.2° F. (49° C.).]

Boiling point of fraction.		Per cent vaporized.
°F.	°C.	
120.2 to 212	49 to 100	32.4
212 to 257	100 to 125	35.2
257 to 302	125 to 150	20.3
302 to 347	150 to 175	5.8
Final boiling point: 372.2	189	1.9
Residue		1.8
Loss		2.6

DISTILLATE.

[Quantity, 100 c. c.; gravity at 60° F. (15.6° C.), 50.0° B. (0.779); color, water white; initial boiling point, 194° F. (90° B.).]

Boiling point of fraction.		Per cent vaporized.
°F.	°C.	
194 to 212	90 to 100	Trace.
212 to 257	100 to 125	26.7
257 to 302	125 to 150	48.6
302 to 347	150 to 175	16.5
347 to 392	175 to 200	5.2
Final boiling point: 401	205	0.6
Residue		1.7
Loss		0.7

SLOP DISTILLATE.

Flash point, 120° F. (48.8° C.) in open cup.

Residuum flashed at 210.2° B. (99.0° C.) in Bureau of Mines cup.

Tests of products made in October, 1916.

GASOLINE.

[Quantity, 100 c. c.; gravity at 60° F. (15.6° C.), 58.8° B. (0.743); initial boiling point, 113°F. (45° C.).]

Boiling point of fraction.		Per cent vaporized.
°F.	°C.	
113 to 112	45 to 100	33.8
212 to 257	100 to 125	35.6
257 to 302	125 to 150	18.9
302 to 347	150 to 175	6.2
Final boiling point: 370.4	188	2.0
Residue		1.7
Loss		1.8

DISTILLATE.

[Quantity, 100 c. c.; gravity at 60° F. (15.6° C.), 49.8° B. (0.780); color, water white; initial boiling point, 199.4° F. (93° C.).]

Boiling point of fraction.		Per cent vaporized.
°F.	°C.	
199.4 to 212	93 to 100	Trace.
212 to 257	100 to 125	24.6
257 to 302	125 to 150	50.9
302 to 347	150 to 175	15.9
347 to 392	175 to 200	5.5
Final boiling point: 401	205	0.9
Residue		1.7
Loss		0.5

TABLE 28.—*Record of heat exchangers, Trumble topping plant at Coalinga.*

Hourly reading on thermometer.	Crude.							Residuum.							Apparatus No.
	Volume in 24 hours, barrels.	Gravity.		Temperature.				Volume in 24 hours, barrels.	Gravity.		Temperature.				
				Ingoing.		Outgoing.					Ingoing.		Outgoing.		
		°B.	Specific gravity.	°F.	°C.	°F.	°C.		°B.	Specific gravity.	°F.	°C.	°F.	°C.	
1	2,176.03	22.5	0.919	65	18.3	108	42.2	1,629.17	18	0.946	296.0	146.6	220	104.4	1
1	2,176.03	22.5	.919	108	42.2	160	71.1	1,629.17	18	.946	377.5	191.9	296	146.6	2
2	3,164.0	22.0	.922	100	37.7								250	121.1	1
2	3,164.0	22.0	.922			193	89.4				350.0	176.6			2
3	2,135.0	22.0	.922	98	36.6								230	110.0	1
3						194	90.0				325.0	162.7			2

SLOP DISTILLATE CONDENSER.

Hourly reading on thermometer.	Distillate.							Temperature of water.				Apparatus No.
	Volume in 24 hours, barrels.	Gravity.		Temperature.				Ingoing.		Outgoing.		
				Ingoing		Outgoing.						
		°B.	Specific gravity.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	
4	408.78	36.0	0.844	215	101.6	100	37.7	82.0	27.7	93	33.8	7
5	397.0	36.0	.844	231	110.5	117	47.2	93.0	33.8	101	38.3	7
6	356.0	36.0	.844	245	118.3	115	46.1	92.0	33.3	100	37.7	7

From the data presented the rate of heat transmission in these apparatus may be computed as follows:

If θ_m=mean temperature difference

Then $\dfrac{\theta_a-\theta_e}{\log_e \dfrac{\theta_a}{\theta_e}}$

Where θ_a=difference between initial temperatures, °F.
θ_e=difference between final temperatures, °F.

If K=British thermal units of heat transmitted per square foot per hour per degree of mean temperature difference

Then $K=\dfrac{F\times S\,(T-T_1)}{H\times\theta_m}$

When F=weight in pounds of fluid imparting heat passing in one hour.
T=initial temperature of F in °F.
T_1=final temperature of F in °F.
S=specific heat of F.
H=heating surface of apparatus, square feet.

Computations of heat transmission in heat exchangers and condensers. Trumble topping plant at Coalinga.

Reading.	Temperature. θ_m.		Name of fluid.	Weight per barrel.	Gravity.		Specific heat.	Name of apparatus.	Heating surface.	Radiating surface, hot space.	Radiating surface, cold space.	K.	K_1.
	°F.	°C.		Pounds.	°B.	Specific gravity.			Square feet.	Square feet.	Square feet.		
1	173.1	78.35	Crude oil	322	22.5	0.919	0.45	Heat exchanger No. 1	876.97	14.12		3.74	
1	173.1	78.35	Residuum	332	18.0	.946	.40	do	876.97		169.56		4.55
1	176.0	80.0	Crude oil	322	22.5	.919	.45	Heat exchanger No. 2	876.97	14.12		4.45	
1	200.0	93.3	Residuum	332	18.0	.946	.40	do	876.97		169.56		4.5
2	156.0	68.8	Crude oil	323	22.0	.922	.45	Heat exchangers Nos. 1 and 2.	1,753.94	28.24		6.5	
3	151.5	66.3	do	323	22.0	.922	.45	do	1,753.94	28.24		4.68	
4	56.0	13.3	Distillate	296	36.0	.844	.50	30-inch condenser No. 7.	519.18			9.9	
5	62.8	17.1	do	296	36.0	.844	.50	do	519.18			9.7	
6	63.0	17.2	do	296	36.0	.844	.50	do	519.18			9.6	

In reading 1 for heat exchanger 1 the values of K and K_1, neglecting losses, should be equal, as the heat given up by the residuum would all be imparted to the crude. However, each fluid loses by radiation of its heat to the surrounding atmosphere.

FUEL CONSUMPTION.

The company was burning natural gas for fuel, and the following record shows the fuel consumption and the products for December, 1916. Prior records of fuel burned are not available, as the gas meter has only recently been installed.

Fuel used and products made in Trumble plant at Coalinga in December, 1916.

Total quantity of crude run, barrels	54,864
Gravity of crude, °B	20.5 to 23.5
Specific gravity of crude	0.931 to 0.913
Gasoline made, barrels	1,994
Gravity of gasoline, °B	59.3
Specific gravity of gasoline	0,741
Distillate made, barrels	1,447
Gravity of distillate, °B	49.7
Specific gravity of distillate	0.780
Slop distillate made, barrels	5,304
Gravity of slop distillate, °B	37.7
Specific gravity of slop distillate	0.836
Total distillate per cent of crude run, per cent	16.0
Residuum made, barrels	45,913
Gravity of residuum, °B	19.7
Specific gravity of residuum	0.935
Loss, barrels	204
Gas fuel used, cubic feet	2,917,000
Gas fuel used per barrel of crude run, cubic feet	53.16

If the gas be considered to have a calorific value of 1,000 British thermal units (252 calories) to a cubic foot, then the record shown above would indicate that the plant was consuming 53,169 British thermal units (13,399 calories) of heat to each barrel of crude oil treated.

THEORETICAL FUEL CONSUMPTION.

The total heat required to make a 16 per cent vapor cut on 1 pound of this oil, assuming no losses occurred in the apparatus, and considering the heat recovered in the exchangers and first run condenser, can be computed as follows.

The results of laboratory distillation previously shown indicate that the oil contains the following average fractions:

Distillation of oil sample.

[Gravity, 21.9° B. (0.922).]

Boiling point of fraction.		Specific gravity of fraction.	Per cent vaporized.		Residuum.		
°F.	°B.		By volume.	By weight.	Specific gravity.	By volume.	By weight.
150 to 275	65.5 to 135	0.733	3.73	2.53	0.929	96.27	97.47
275 to 300	135.0 to 148.8	.755	2.14	1.53	.934	94.13	95.94
300 to 350	148.8 to 176.6	.810	4.92	3.67	.940	89.21	92.27
350 to 400	176.6 to 204.4	.837	2.50	1.96	.943	86.71	90.31
400 to 475	204.4 to 246.1	.848	2.71	2.11	.945	84.00	88.20

Assume that specific heat of the oil=0.45, approximately.
latent heat of distillates=125 B. t. u., approximately.
specific heat of the vapors=0.50, approximately.
oil leaves the first run condenser at 275° F. (135° C.).

Then the heat required to make the cuts shown above would be as itemized:

		B. t. u
Heat 0.975 pound of oil 275 to 300° F. (135 to 148.8° C.)	0.975 (275–300)× 0.45=	11.92
Evaporate 0.015 pound vapors	.015×125 =	1.87
Superheat 0.0406 pound vapors 275 to 300° F. (135.0 to 148.8° C.)	.0406 (275–300)× .5 =	0.57
Heat 0.959 pound oil 300 to 350° F. (148.8 to 176.6° C.)	.959 (300–350)× .45=	21.58
Evaporate 0.0367 pound vapors	.0367×125 =	4.58
Superheat 0.0773 pound vapors 300 to 350° F. (143.8 to 176.6° C.)	.0773 (300–350)× .5 =	1.96
Heat 0.923 pound oil 350 to 400° F. (176.6 to 204.4°C)	.923 (350–400)× .45=	20.80
Evaporate 0.019 pound vapor	.019×125 =	2.38
Superheat 0.096 pound vapors 350 to 400° F. (176.6 to 204.4° C.)	.096 (350–400)× .5 =	2.40
Heat 0.903 pound oil 400 to 475° F. (204.4 to 246.1° C.)	.903 (400–475)× .45=	33.90
Evaporate 0.021 pound vapors	.021×125 =	2.63
Superheat 0.117 pound vapors 400 to 475° F. (204.4 to 246.1° C.)	.117 (400–475)× .5 =	4.38
The total heat required to top 1 pound of this oil at 100 per cent efficiency		=108.907

An oil of 22° B. (0.922) gravity weighs 322.5 pounds to the barrel.

Therefore at 100 per cent efficiency to top 1 barrel of this oil would require: 322.5× 108.907=35123.47 B. t. u., or 8,840 calories.

OVER-ALL EFFICIENCY OF TOPPER BATTERY.

Actually, however, 53,169 British thermal units (13,399 calories) is used per barrel of oil topped. The over-all efficiency of the topper is then

$$\frac{35123.47}{53169}=\frac{8840 \text{ calories}}{13399 \text{ calories}}=66.0 \text{ per cent.}$$

COST OF PLANT.

This plant as originally constructed, excluding the tankage, cost approximately $22,450, or about $7.48 per barrel of normal daily capacity. This cost can be segregated as follows:

Itemized cost of plant.

1 evaporator	$600
2 heaters and brickwork	3,000
3 36-inch heat exchangers, at $500 each	1,500
6 30-inch condensers, at $425 each	2,550
2 separators, at $850 each	1,700
4 dephlegmators, at $600 each	2,400
1 oil catcher	200
3 1,000-barrel tanks, at $1,008 each	3,024
1 10,000-barrel tank	5,000
6 150-barrel tanks, at $200 each	1,200
4 1,000-barrel tanks, at $1,500 each	6,000
Pipes and fittings	5,000
Foundations, erection, and excavation	5,500
Total	37,674

THE MARTINEZ PLANTS.

In 1915 to 1916, the company controlling the Trumble patent rights constructed a large refinery at Martinez, the bay terminal of its 8-inch oil line from the Coalinga fields.

In connection with this refinery a Trumble topping plant consisting of one battery of two heaters was constructed, followed by a second one of the same size.

NO. 1 PLANT.

The No. 1 plant in general resembles the ones previously described, separations of the different distillates being accomplished by fractional reheating in the separators, prior to the installation of the dephlegmators. An important addition, however, is the auxiliary evaporator columns by means of which the entering crude oil is also heated in steps. In former plants the light vapors evolved in the pipe heaters were of necessity superheated to the boiling point of the heaviest fractions before entering the evaporator, resulting in the consumption of unnecessary fuel and, in the writer's opinion, possible disassociation of some of the light vapors.

By means of the evaporating column these lighter vapors are removed at a temperature close to their boiling point, the residual oil continuing through the plant for further treatment.

DETAILED DESCRIPTION OF APPARATUS, NO. 1 PLANT.

HEATERS.

The plant consists of one battery of two heaters each containing six horizontal rows of 12 lapwelded 4-inch pipes 18 feet 9 inches long connected at one end by flanged return bends and at the other by

screwed returns. These pipes are bricked within the heater walls and the fire gases are forced by appropriate baffle walls to make three passes over them in traveling to the annular space around the evapo-

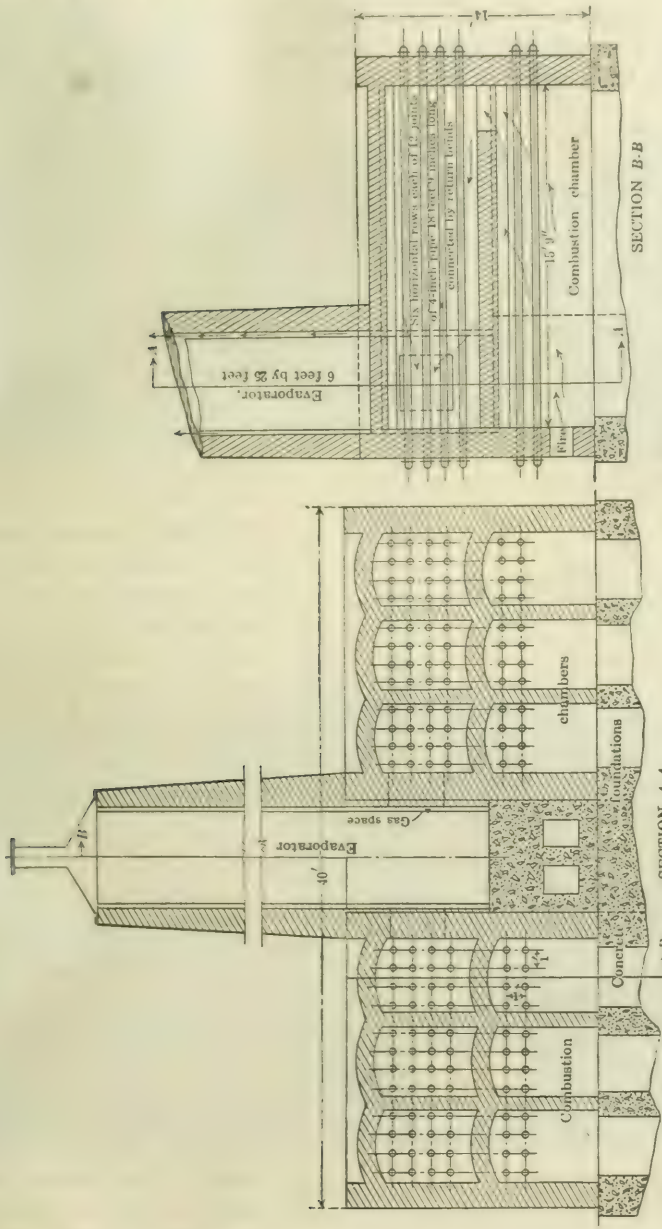


FIGURE 32.—Pipe retorts and settings of Trumble plant No. 1, at Martinez. Outside heating surface of pipes, 2,728.7 square feet; inside heating surface, 2,430.3 square feet.

rator. The return bends exposed outside the furnace walls are carefully insulated with asbestos covering. Figure 32 shows the construction of these heaters. A general view of the No. 1 plant and a view

of the heater and evaporator with the column is shown in Plates XLIV, *A* and *B*, and Plate XLV, *A*.

EVAPORATOR.

The construction of the evaporator, 6 by 25 feet, fed by these heaters, is identical with that of evaporators previously described. The circular brick wall forms an annular space around the evaporator for the escaping gases, and extends to the removable top of the evaporator, where it is surmounted by a short stack to carry away these gases. Adjacent to this wall, and connected by flanges to the three vapor take-off lines of the evaporator, is mounted a similar apparatus of 48-inch diameter incased in a steel shell of slightly greater diameter, forming a space for the vapors leaving the evaporator which supply heat to the column. Figure 33 shows this construction.

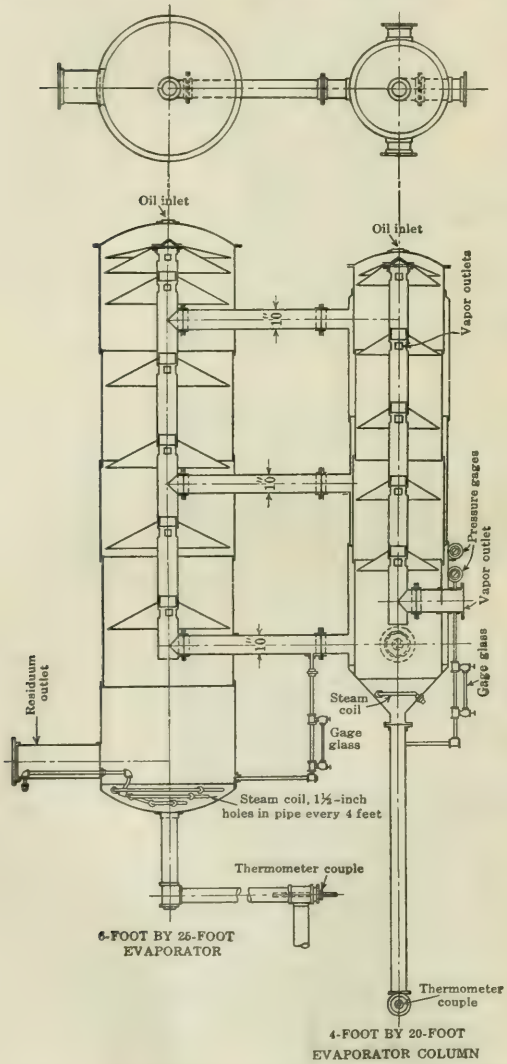


FIGURE 33.—Evaporator and evaporator column, Trumble plant No. 1, at Martinez. Evaporator heating surface, 471 square feet.

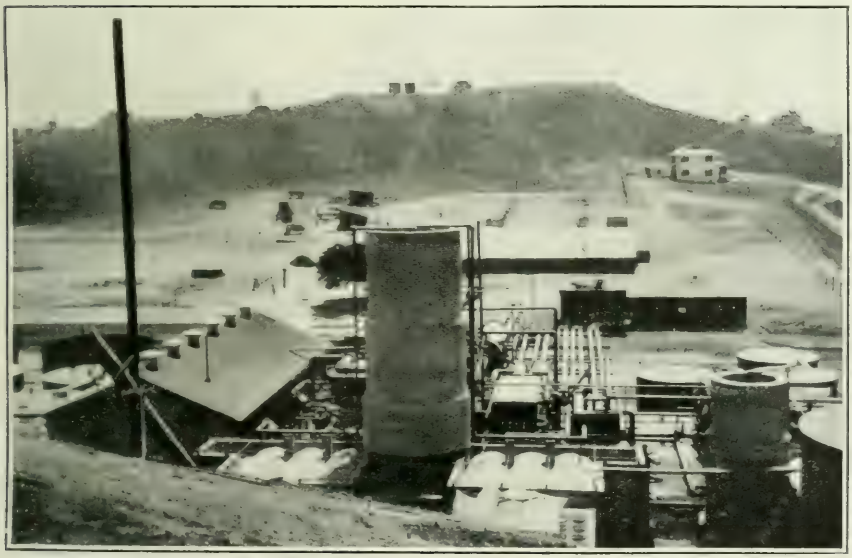
OIL CATCHER.

An oil catcher to return to the evaporator heavy oils mechanically entrained with the vapors is placed in the vapor line from the column. (See fig. 30, p. 116.)

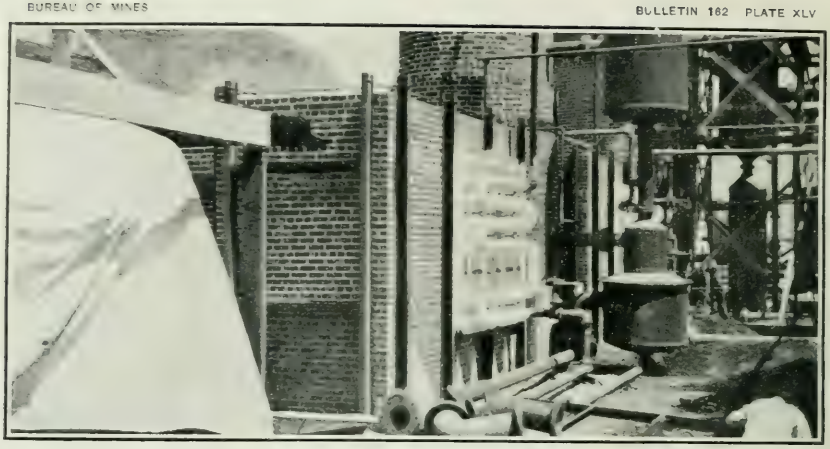
SEPARATOR.

Four separator boxes similar to those of the Coalinga plant are provided. The heating tubes, however, are 18 feet long instead of 14 feet, making the longitudinal dimension of the box 4 feet greater. Figure 28 (p. 113) shows this box, and Plate XLVI, *B* (p. 134), shows

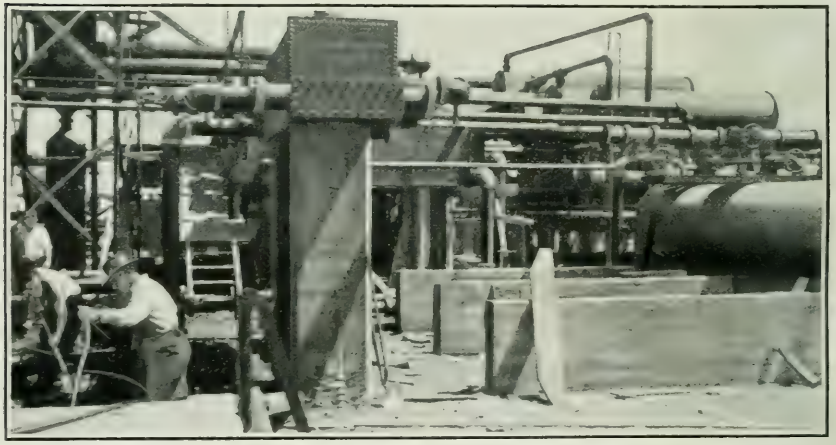
A. PIPE RETORTS AND EVAPORATOR WITH EVAPORATOR COLUMN. TRUMBLE NO. 1 PLANT. MARTINEZ, CAL.



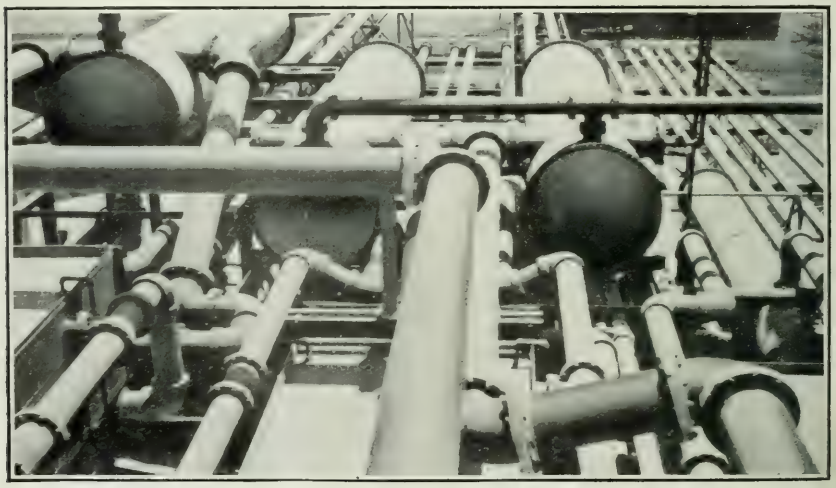
B. TRUMBLE NO. 1 PLANT, MARTINEZ, CAL. NOTE JACKETED LINE COOLERS IN BACKGROUND.



A. VIEW OF PIPE RETORTS SHOWING INSULATED RETURN BENDS. MARTINEZ TRUMBLE NO. 1 PLANT.



B. CONDENSERS WITH HEAT EXCHANGERS IN FOREGROUND. MARTINEZ TRUMBLE NO. 1 PLANT.



C. VIEW OF CONDENSERS AND JACKETED LINE COOLERS. MARTINEZ TRUMBLE NO 1. PLANT.

the boxes in place, with the interconnecting piping and forward manifolds and the steam inlet valves.

DEPHLEGMATORS

Five small dephlegmators and one large one are used in this installation as shown on the accompanying vapor flow chart. The original construction did not include these, their need developing after operation. Each consists of the type illustrated in figure 29 (p. 115), and described in the discussion of the Coalinga plant. The small ones are 3 feet in diameter by 8 feet high, and the large one 6 feet in diameter by 16 feet high. Vapors entering a dephlegmator drop their heavier fractions to the bottom as condensate and leave at the top as a more homogeneous product.

THIRTY-INCH CONDENSERS.

Five 30-inch condensers are provided, constructed as previously described. Each contains 59 2-inch tubes 18 feet long, expanded into double tube sheets. These double tube sheets reduce to a minimum the possibility of the fluids mixing from leaky tubes during the exchange of heat. Liquids or vapor within these tubes make four passes through the apparatus while the surrounding liquids or vapors make two passes. The principle of counterflow is only partly developed in this condenser, the larger type next described more nearly reaching this desired condition.

FORTY-EIGHT-INCH HEAT EXCHANGERS AND CONDENSERS.

Three 48-inch condensers and five heat exchangers of similar construction are also used in which the liquids or vapors within the tubes make four passes through the tubes. They contain 180 2-inch tubes, and by means of a horizontal baffle the liquid surrounding the tubes makes two passes over the tubes in its course through the apparatus. Figure 34 illustrates these condensers and heat exchangers. Plates XLV, *B*, XLV, *C* (p. 133), and XLVI, *A* (p. 134), show the condenser and heat exchangers with the interconnecting piping.

JACKETED LINE COOLERS.

Jacketed line coolers consisting of 150 feet of 6-inch pipe within 9⅝-inch pipe are used in this plant to cool the various products before they are sent to storage.

The steam used in connection with the operation is supplied by the main refinery boiler plant of several 250-horsepower Heine boilers. A separately fired superheater, with a capacity per hour of raising 4,000 pounds of steam, containing not more than 1 per cent water to a temperature of 750° F. from a boiler pressure of 30 pounds, furnishes the necessary superheat.

OPERATION OF NO. 1 PLANT.

The crude-oil flow sheet (fig. 35) shows the flow of incoming crude and outgoing residual oil through the apparatus. The crude oil is pumped by means of Dow double duplex 10 by 10½ by 10½ by 12 pumps into the three 48-inch diameter condensers 1, 2, and 3 in

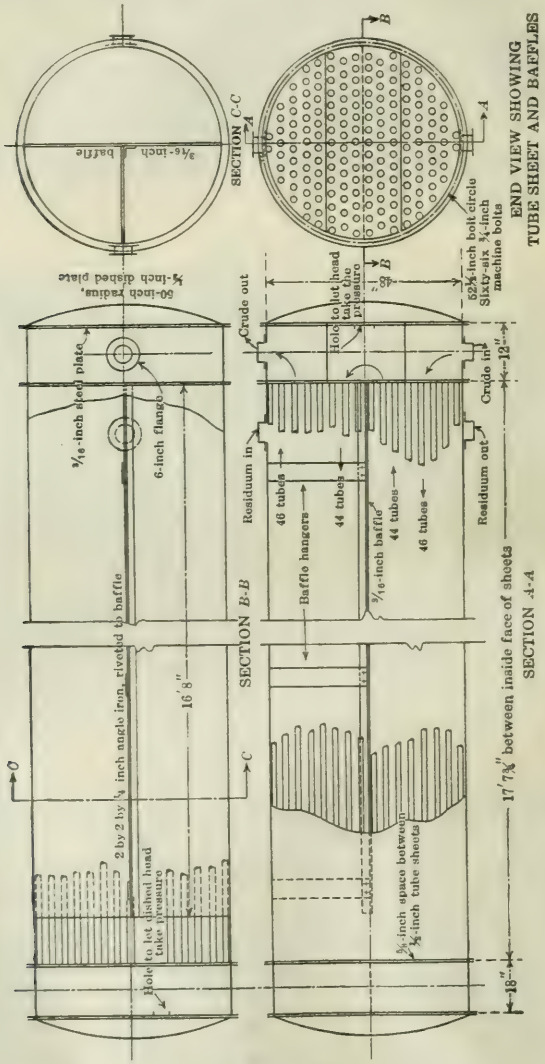
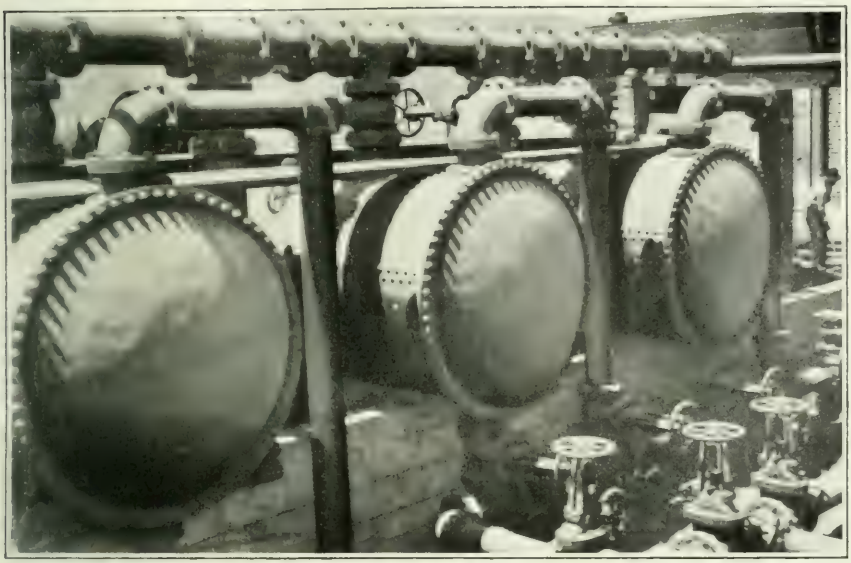
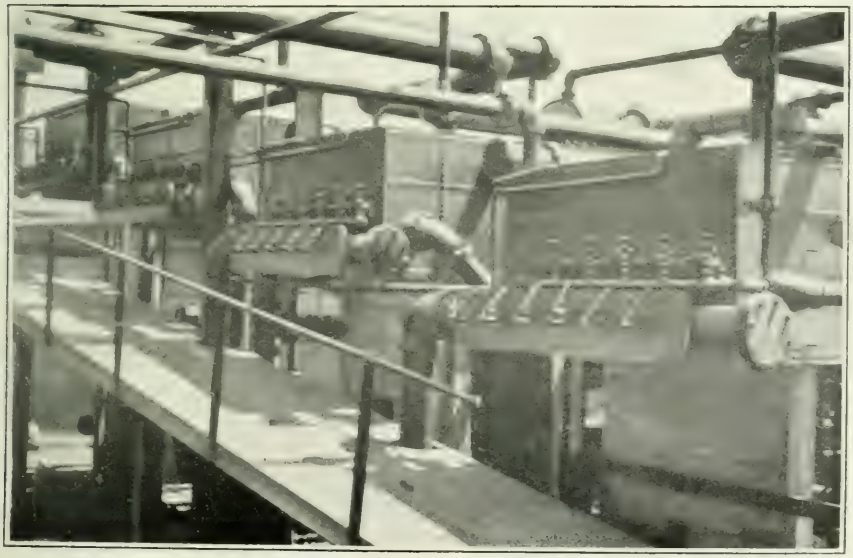


FIGURE 34.—Forty-eight-inch heat exchangers and condensers in Trumble plant No. 1, at Martinez. End view shows tube sheet and baffles. Evaporator has 180 2-inch pipes 18 feet long rolled into double tube sheets. Outside surface of tubes, 1,660.6 square feet; inside surface, 1,501.9. Radiating surface of heating element, 222 square feet; of heated element, 65 square feet.

parallel, passing through the tubes countercurrent to and in heat exchange with the vapors surrounding them. Thence the crude passes in series into the heat exchangers 4, 3, 2, and 1 through the tubes, being heated by the outgoing residuum from the bottom of the evaporator. From the heat exchangers the warm crude enters



A. HEAT EXCHANGERS. MARTINEZ TRUMBLE NO. 1 PLANT.



B. SEPARATORS SHOWING STEAM VALVES AND INTERCONNECTING PIPING. MARTINEZ TRUMBLE NO. 1 PLANT.

heater 1 at the bottom row of 4-inch pipes adjacent to the evaporator, passing back and forth and upward through each row and thence into the top of the evaporator column. In the two lower rows the oil is under direct fire, whereas the four rows above are heated by the combustion gases on their second and third passes from the furnace. As the crude enters the evaporator column and flows in a thin film down its sides, heated by hot vapors from the evaporator, light vapors are separated and the liquid, settling at the bottom, returns to a similar pump and is pumped through heater 2 (as described above) to the top of the evaporator. As the liquid flows down the sides of the evaporator, being heated by the flue gases, an additional

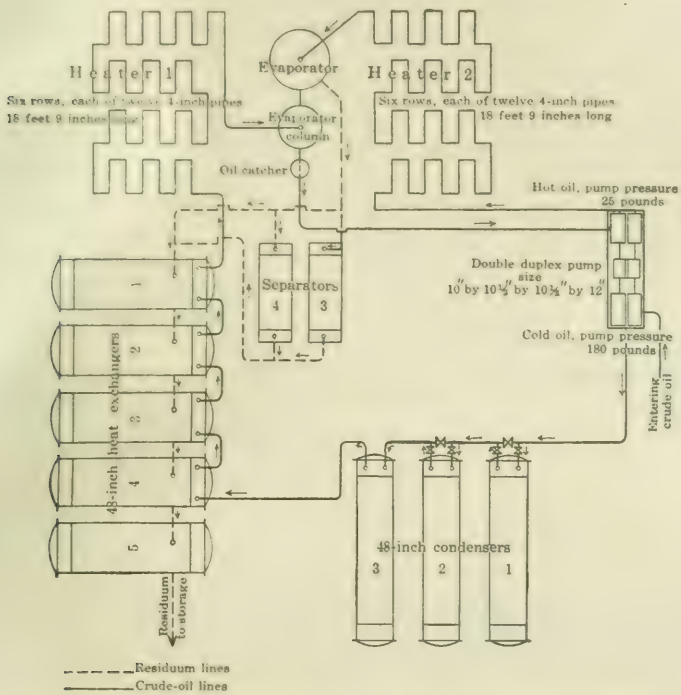


FIGURE 35.—Crude-oil and residuum flow sheet, Trumble plant No. 1, Martinez.

heavier vapor cut is made and the residual oil, collecting in the bottom, gravitates in series through the heat exchangers 1, 2, 3, 4, and 5 surrounding the tubes. In heat exchanger 5 cooling water circulates through the tubes, and the residuum thus cooled flows to storage. By controlling the fire and rate of flow of oil through the plant a residual fuel oil of any desired specification may be obtained. By means of a by-pass arrangement any part of the residuum from the bottom of the evaporator is forced to pass through the tubes of separators 3 and 4, furnishing a heat medium for the redistillation of distillates being rerun.

The vapor flow sheet (fig. 36) shows the flow of the vapors and distillates from the plant. The light vapors from the evaporator column pass through the oil catcher; thence as a heating agent through the tubes of separator 1; and thence to the 48-inch condenser No. 3, around the tubes, and into a jacketed line cooler, returning to the first liquid compartment of separator 1 for redistillation. A water trap at the end of the jacketed line removes the water, which, if it entered the separators, would make control of them difficult, on account of the resulting unsteadiness of pressure. Passing through

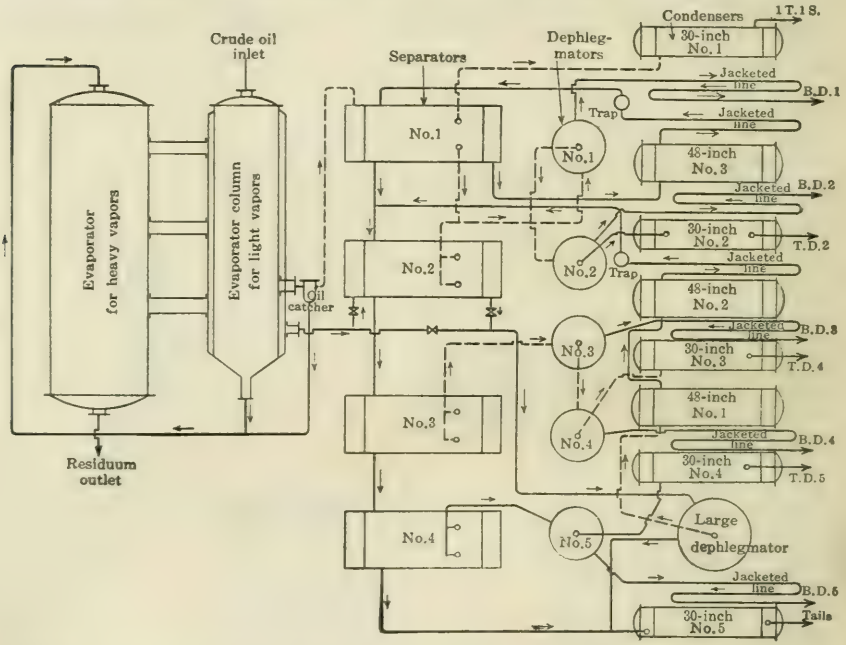


FIGURE 36.—Vapor and distillate flow sheet for Trumble plant No. 1 at Martinez. *1 T. 1 S.*—first top, No. 1 separator; *B. D. 1*—bottom, dephlegmator *1; B. D. 2*—bottom, dephlegmator *2; T. D. 2*—top, dephlegmator *2; B. D. 3*—bottom, dephlegmator *3; T. D. 4*—top, dephlegmator *4; B. D. 4*—bottom, dephlegmator *4; T. D. 5*—top, dephlegmator *5; B. D. 5*—bottom, dephlegmator *5*. ..... vapor lines. ——— distillate lines.

separator 1 this light condensate gives two vapor cuts, and the distillate bottom remaining flows to the first compartment of separator 2 and through this separator, giving two more vapor cuts.

The bottoms from separator 2 flow through separator 3 to separator 4. Two vapor cuts are taken from each and the bottom distillate of separator 4 joins the bottoms from the large dephlegmator and passes through the tubes of 30-inch condenser 5 to storage. The vapors from the evaporator after passing around the evaporator column enter the tubes of separator 2 as a heat medium for reevapo-

rating the liquids contained, and pass thence to the large dephlegmator, entering near the bottom. The lighter vapors leave at the top and a heavy cut of gas oil collects at the bottom, whence it passes through 30-inch condenser 5 with the bottoms of separator 4 to storage. The separators are thus relieved of handling this heavy cut and are able to handle the remaining distillates satisfactorily with the heat regenerated and the addition of very little steam. Before installing this dephlegmator the separators were overtaxed, and even with the help of considerable steam it was impossible to cut the gravity of the bottoms low enough.

Top vapors from the dephlegmator pass in parallel through the 48-inch condensers 1 and 2 around the tubes, and thence into a jacketed line cooler, the condensate mixing with the bottoms of separator 1 and entering the first liquid compartment of separator 2, to be rerun. The first vapor cut of separator 1 combines with the first and second tops of separator 2 and passes into small dephlegmator 1 near the bottom, and thence out the top and into dephlegmator 2 near the bottom. The bottoms of dephlegmators 1 and 2 each pass through a jacketed line cooler to storage. The vapor top of dephlegmator 2 passes around the tubes of 30-inch condenser 2, and thence to storage. The first and second tops and vapor cuts of separator 3 combine and pass through small dephlegmators 3 and 4 in series. Condensate from each dephlegmator is cooled in jacketed lines and passes to storage, whereas the vapor top of dephlegmator 4 passes around the tubes of 30-inch condenser 3 and to storage.

The two tops of separator 4 pass through dephlegmator 5; thence the vapor top of dephlegmator 5 passes through 30-inch condenser 4 to storage. The bottoms of the dephlegmator go through a jacketed line to storage. In all jacketed lines the distillates travel countercurrent to the circulating water in the jacket. These small dephlegmators were added to the original installation because the close fractions desired could not be obtained by rerunning in the separators alone.

NO. 2 PLANT.

The second plant constructed at this refinery is the most recent and modern installation of this type, and is therefore fully described.

The apparatus is so arranged that the vapors are subjected to a fractional cooling process, the distillates thus obtained being rerun in the separators to bring them to the desired specifications. The operation of the separators is greatly facilitated by this method. (See plates XLVII (p. 138) and XLVIII (p. 140).)

Data on apparatus shown in Pls. XLVII and XLIII.

No.	Part.	Size.	Number required.
1	Evaporator	6 feet by 25 feet	1
2	Dephlegmator	6 feet by 16 feet	6
3	Heat exchanger	4 feet by 20 feet 9 inches	3
4	Condenser	2 feet 6 inches by 23 feet	8
5	Cooler	2 feet 6 inches by 20 feet 3¼ inches.	6
6	Separator	6 feet by 18 feet	3

DETAILED DESCRIPTION OF APPARATUS, NO. 2 PLANT.

EVAPORATOR AND HEATERS.

The No. 2 plant consists of one battery of two heaters (Pl. XLIX, *A*, p. 142) of the same construction and size as those of the No. 1 plant except that the two lower rows of pipes in each heater are equipped with cast-iron rings fitting closely together. The expectation was that these rings would insure a more even heat of the pipes under direct fire and give them additional strength. The oil from the heaters flows to the top of a single evaporator similar in size and construction to the evaporator in the No. 1 plant. The three vapor take-off lines are connected by a manifold, and the evaporator column is eliminated. (See Pl. L, *A*, p. 143.)

HEAT EXCHANGERS.

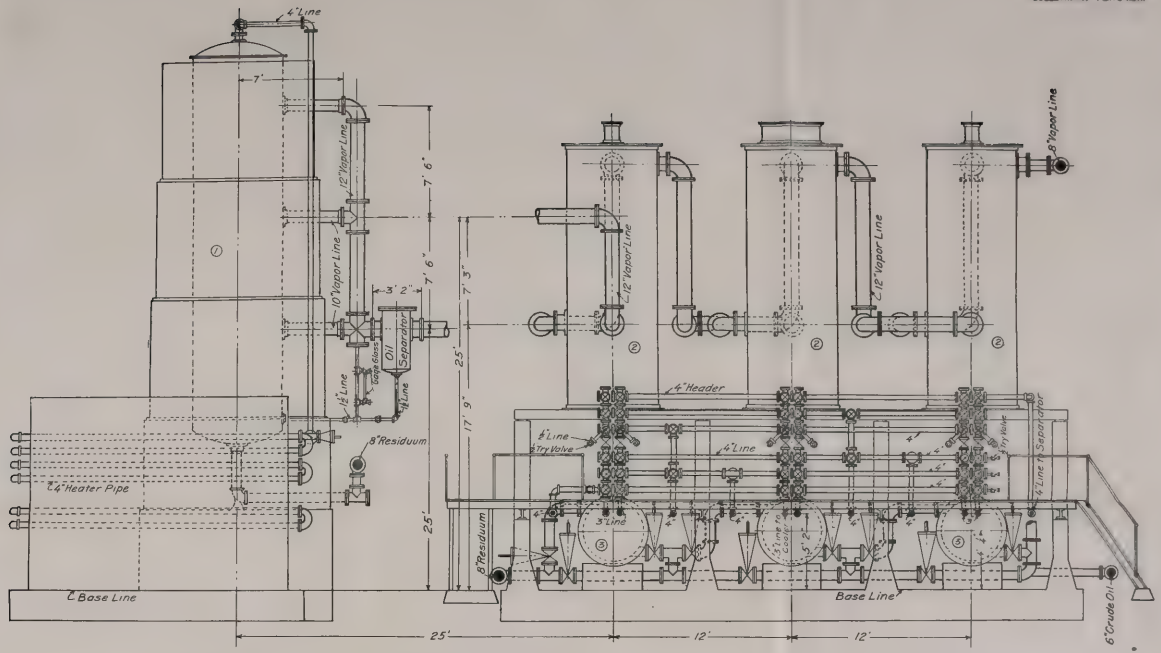
Five double tube sheet heat exchangers 48 inches in diameter containing one hundred and seventy-eight 2-inch boiler tubes 18 feet long are provided. They are equipped as before with removable dished heads to facilitate inspection and repair of the apparatus. Fluids within the tubes make six passes through the heat exchangers, whereas the surrounding fluid makes two passes. As indicated in figure 37, approximately two-thirds of the fluid within the tubes flows counter current to the fluid surrounding the tubes during operation. (See Pl. XLIX, *B*, p. 142.)

SEPARATORS.

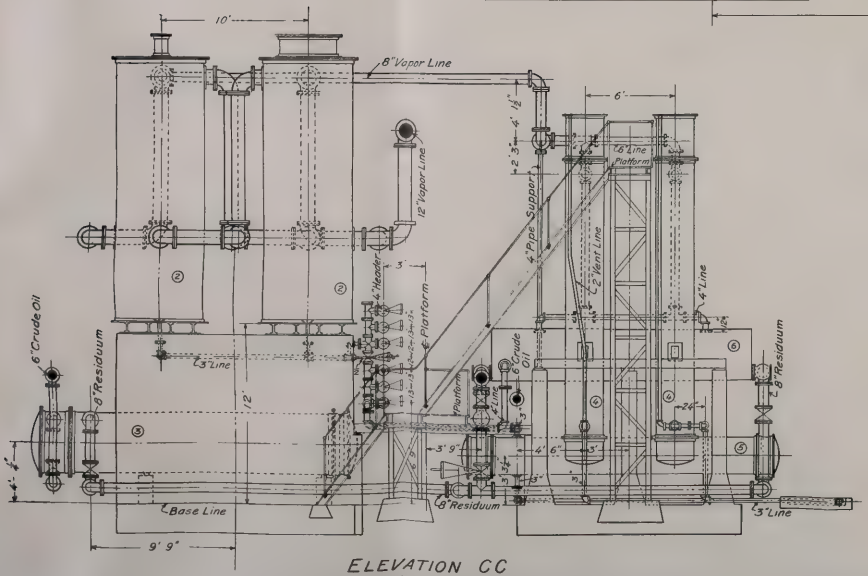
Three separator boxes identical with those of the No. 1 plant are provided for the rerunning of distillates containing undesirable fractions. Plate L, *A* (p. 143) shows these boxes in place mounted for a gravity flow between them.

THIRTY-INCH COOLERS.

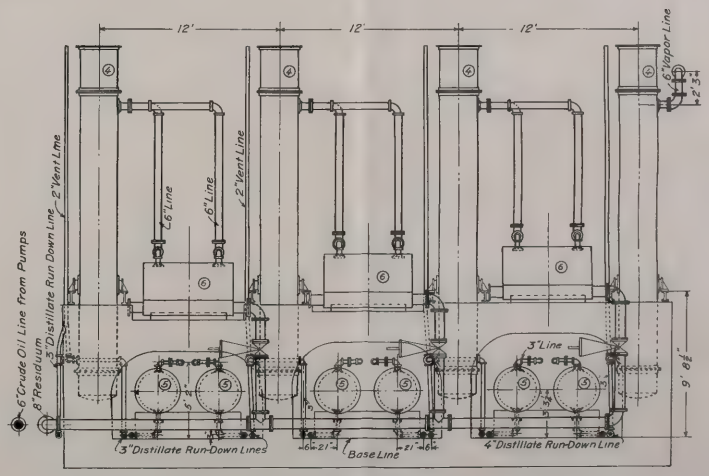
Six horizontal coolers, 30 inches in diameter, similar to those of the first plant and containing sixty-two 8-inch tubes 18 feet long are



ELEVATION AA



ELEVATION CC



ELEVATION BB

ELEVATIONS OF GENERAL ARRANGEMENT AND OF VAPOR AND DISTILLATE PIPING, NO. 2 TRUMBLE TOPPING PLANT, MARTINEZ, CAL. FOR LIST OF PARTS SEE TABLE ON PAGE 140.

used for cooling the distillates before they pass to storage. (See fig. 38 and Pl. L, *A*.)

THIRTY-INCH VERTICAL CONDENSERS.

Eight vertical condensers, 30 inches in diameter, containing seventy 2-inch tubes are installed. Their construction is identical

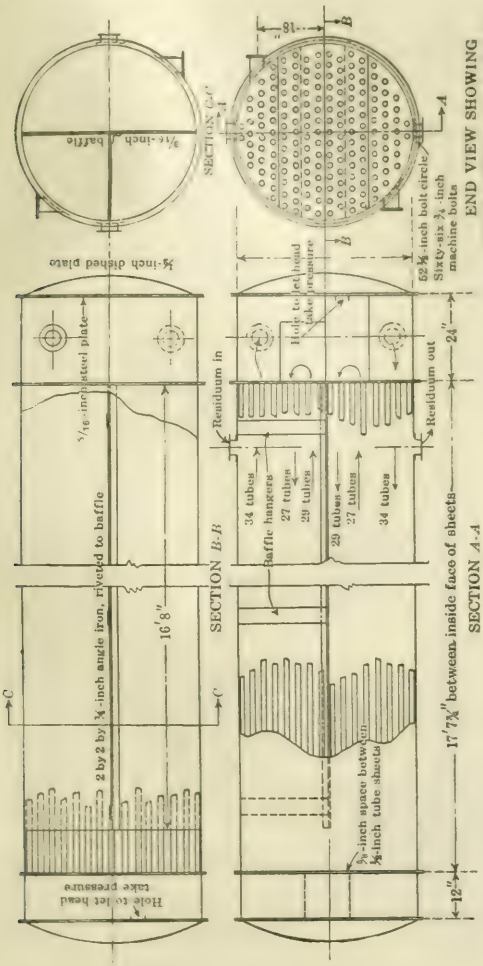


FIGURE 37.—Forty-eight-inch heat exchangers in Trumble plant No. 2, Martinez. End view shows tube sheet and baffles. Has one hundred and seventy-eight 2-inch tubes 18 feet long rolled into double-tube sheets. Outside heating surface of tubes, 1,645 square feet; inside surface, 1,488. Radiating surface of heating element, 222 square feet; of heated element, 65 square feet.

with that of the coolers described above except that the top heads are removed. (See Pl. XLIX, *B*, p. 142.)

DEPHLEGMATORS.

Six dephlegmators, 6 by 16 feet, of the type illustrated in figure 29 (p. 115) and described in connection with the first plant furnish the means for fractionally cooling the vapors. (See Pl. XLIX, *B*.)

OIL CATCHER.

An oil catcher in the main vapor line from the exchanger returns heavy oils mechanically carried to the evaporator. This apparatus is shown in figure 30 (p. 116).

The steam used in this plant is supplied and superheated by the same installation that furnishes steam to the No. 1 plant.

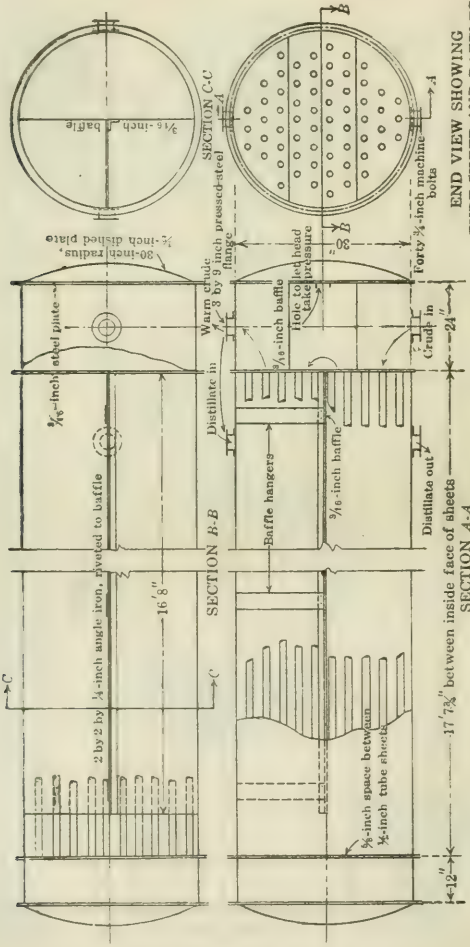
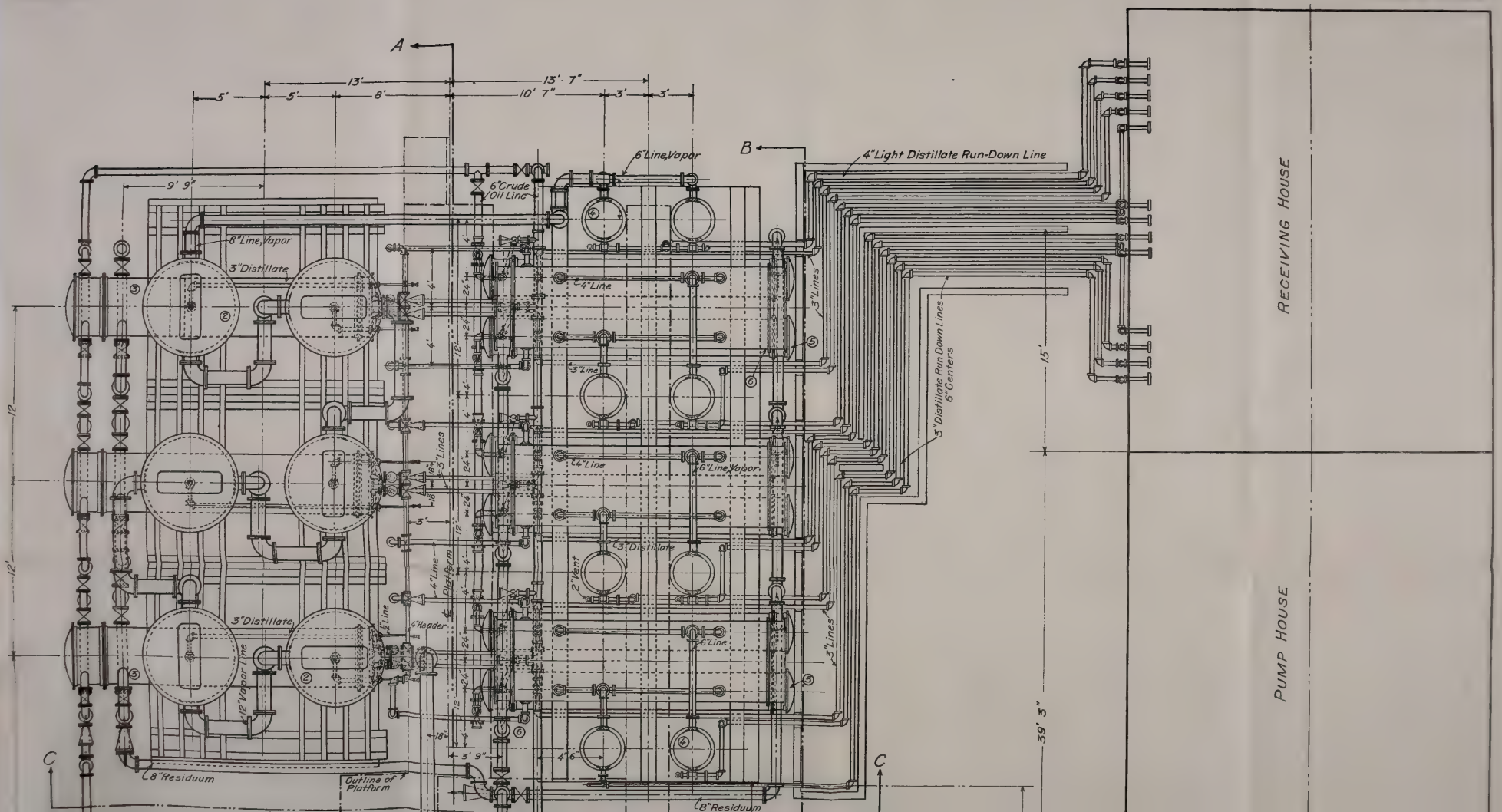


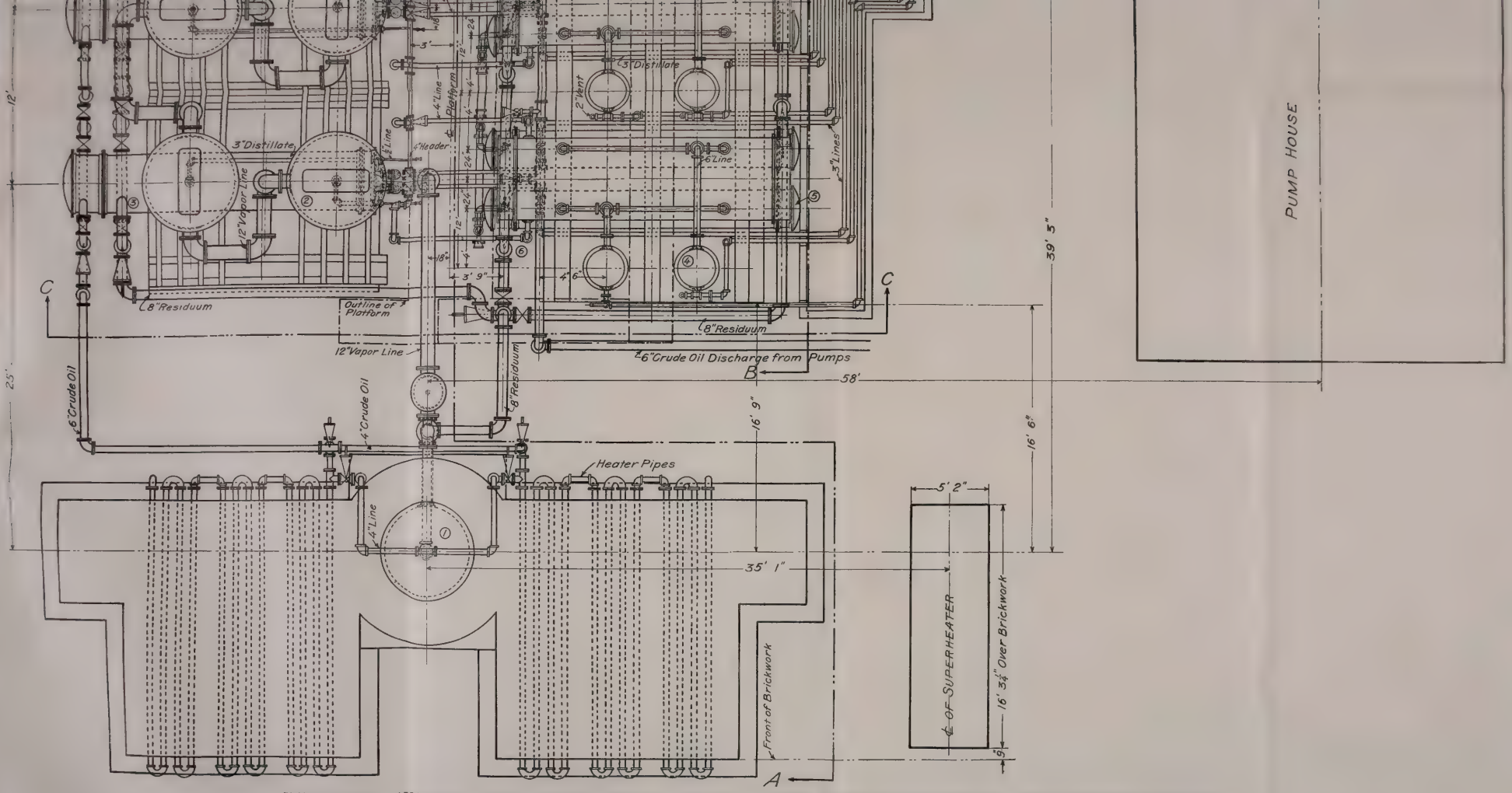
FIGURE 38.—Thirty-inch distillate cooler in Trumble plant No. 2, Martinez. End view shows tube sheet and baffles Has sixty-two 2-inch tubes 18 feet long rolled into double-tube sheets. Outside surface of tubes, 574 square feet; inside surface, 520. Outside radiating surface, 139 square feet; inside radiating surface, 30 square feet.

OPERATION OF NO. 2 PLANT.

The flow sheet comprising figure 39 shows the flow of the oil and residuum through the plant.

Crude oil entering the plant is forced by a Dow duplex pump, 12 by 10 inches by 12 feet, through the six coolers in parallel, passing through the tubes in heat exchange with the distillates going to storage. The piping arrangement permits any cooler to be isolated from the system for repairs. From the coolers the warm oil passes in series through the heat exchangers 4, 3, 2, and 1, circulating


A
B
C
13'
13' 7"
5'
5'
8'
10' 7"
3'
3'
9' 9"
6" Line, Vapor
6" Crude Oil Line
4" Light Distillate Run-Down Line
8" Line, Vapor
3" Distillate
4" Line
3" Line
3" Lines
3" Distillate Run Down Lines 6" Centers
6" Line, Vapor
3" Distillate
2" Vent
4" Line
Platform
4" Header
6" Line
12" Vapor Line
8" Residuum
Outline of Platform
3' 9"
4' 6"
12'
15'
39' 3"
RECEIVING HOUSE
PUMP HOUSE



PLAN OF GENERAL ARRANGEMENT AND OF VAPOR AND DISTILLATE PIPING, NO. 2 TRUMBLE TOPPING PLANT, MARTINEZ, CAL. FOR ELEVATION SEE PLATE XLVI.

through the tubes countercurrent to the outgoing residuum surrounding them.

The oil thus preheated flows to the heaters, dividing to the right and left heaters. Thence, forced by the pump pressure, it passes back and forth through the coils under fire, and then passes upward, discharging at slight pressure into the top of the evaporator. The evaporator is heated by escaping flue gases, and the hot oil after

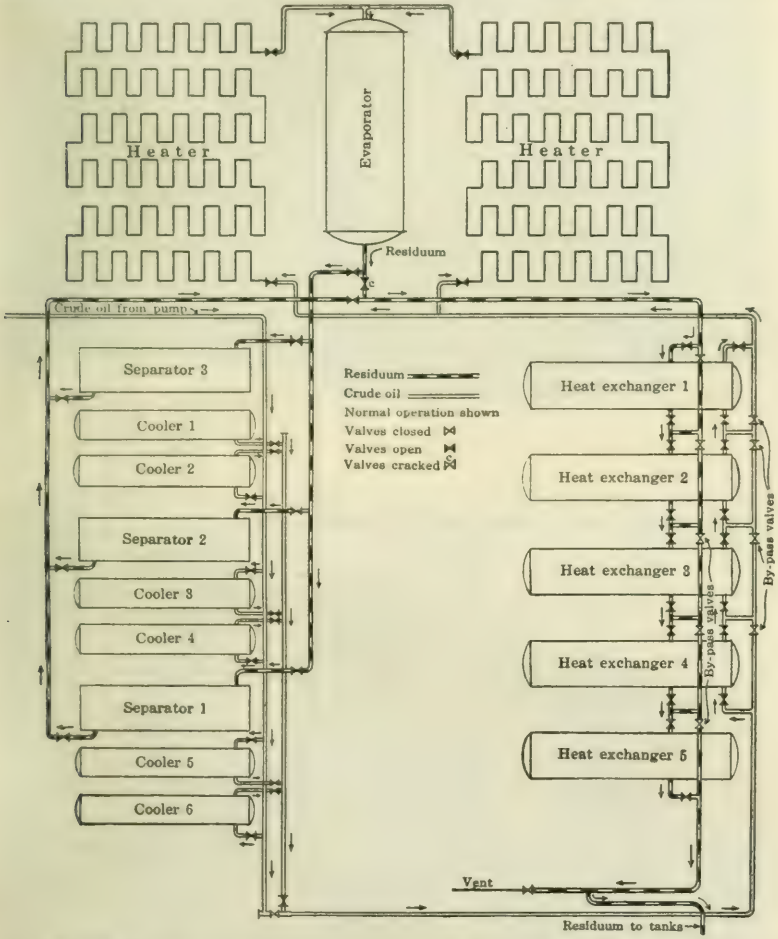


FIGURE 39.—Crude-oil and residuum flow sheet for Trumble plant No. 2, Martinez.

parting with its vapor in the downward course along the sides of the apparatus is drawn from the bottom as residuum. Although regulating valves are provided in the 4-inch lines to the evaporator top, in practice they are seldom needed, the column of oil furnishing sufficient head to insure steadiness of pressure on the coils.

The residuum gravitates through separators 1, 2, and 3 in series, passing through the tubes as a heating medium for the distillates being rerun.

The chart for the flow of cooling water is given in figure 40, which shows that a part of the cooling water passes through the dephlegmators before entering the condensers. The pipes from the dephlegmators discharge into the open top of the condenser.

Figure 41, comprising a flow sheet for flue gases, shows that the hottest gases encounter the two coldest coils in their first pass, whereas

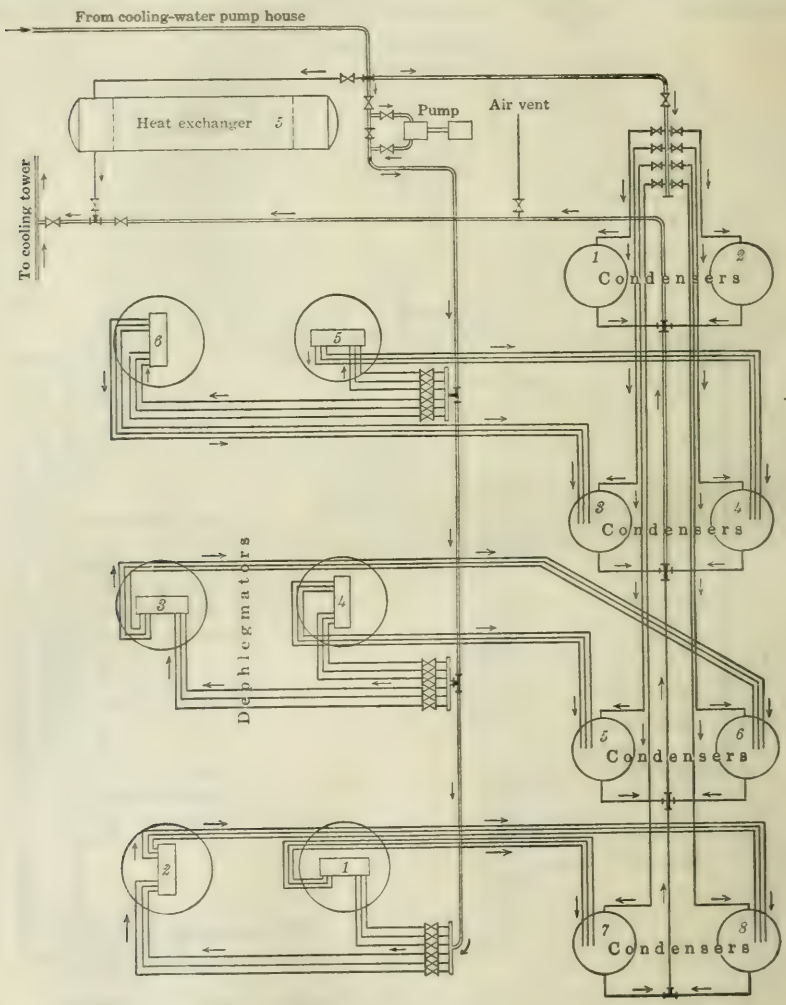
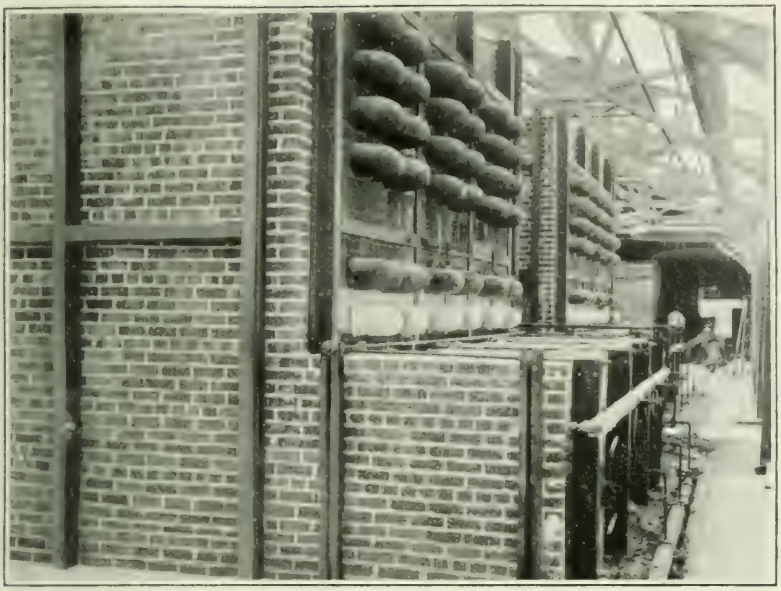
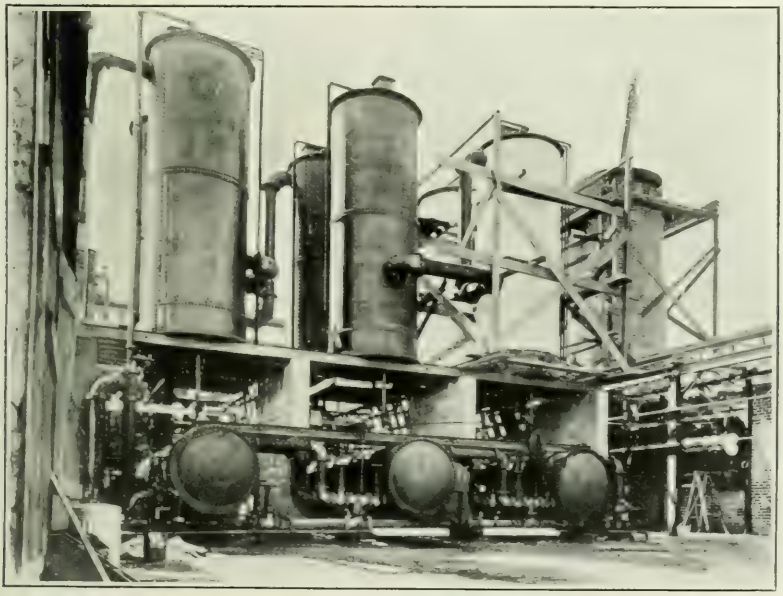


FIGURE 40.—Cooling-water flow sheet, Trumble plant No. 2, at Martinez.

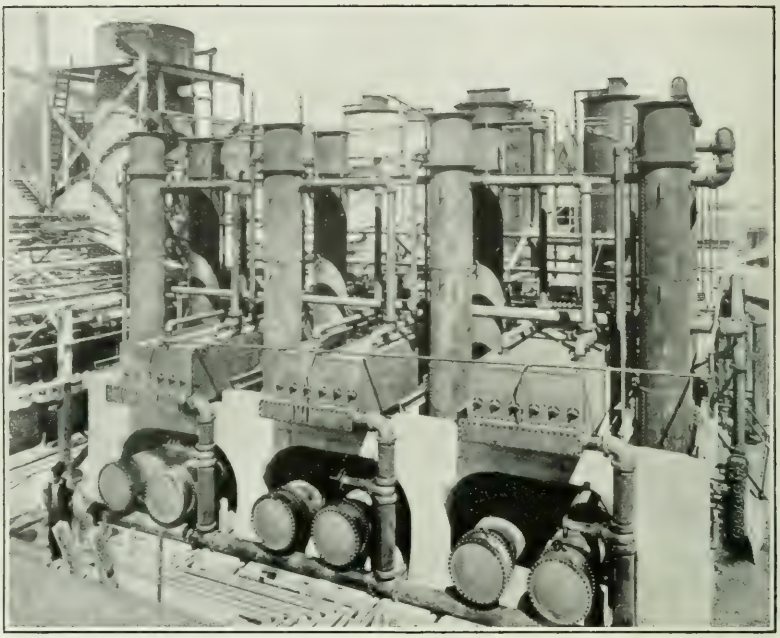
in the second and third passes the gases surround the upper four coils; that is, the flue gases do not flow countercurrent to the oil within the pipes, and it is impractical to pump the oil from the upper coil downward through the heater, owing to danger of gas pockets and consequent danger of burning the tubes. Consequently, in the writer's opinion, a heater firing downward with a forced draft, or with the



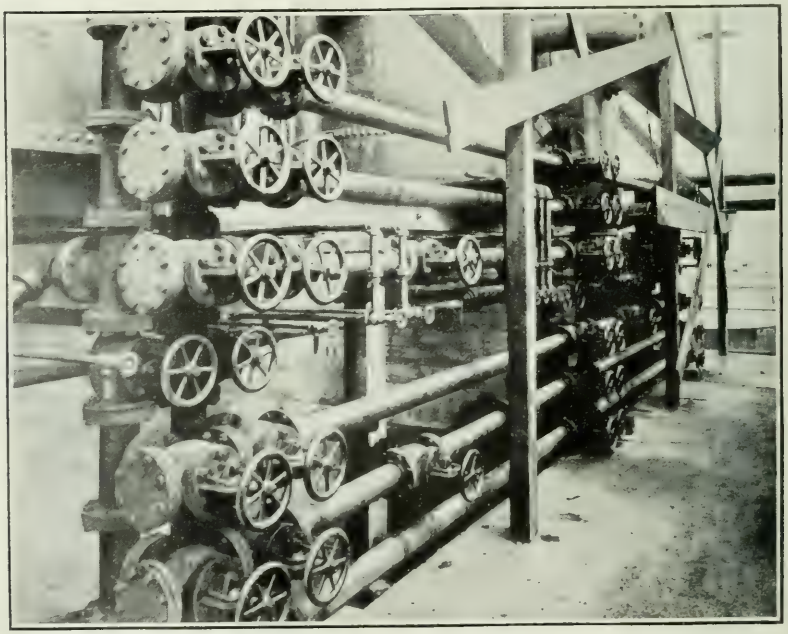
A. REAR VIEW OF PIPE HEATERS SHOWING DUTCH OVENS. TRUMBLE NO. 2 PLANT.



B. GENERAL VIEW OF MARTINEZ TRUMBLE NO. 2 PLANT SHOWING DEPHLEGMATOR AND HEAT EXCHANGER INSTALLATION.



A. GENERAL VIEW OF TRUMBLE NO. 2 PLANT. NOTE RUN DOWN LINES TO THE TAILHOUSE IN THE FOREGROUND.



B. VIEW OF VALVE ASSEMBLY CONTROLLING OPERATION. TRUMBLE NO. 2. PLANT.

baffles so arranged as to force the hottest gases up over the upper coils and then down over the first coils, similar to the arrangement of the last Vernon heater, would be an improvement. The counterflow thus established would result in a more even heating of the oil and would permit the attainment of a much lower stack temperature with the attendant fuel saving. With this arrangement part of the combustion gases could be diverted to surround the evaporator from their first or second pass through the furnace while the major portion of the gases would take the arranged course through the heater to the stack. The function of the gases surrounding the evaporator is primarily to sustain the heat within the apparatus during the separation of the vapors, and therefore their temperature need not be above that of the oil from the heaters.

With the present arrangement, however the stack temperature can not be reduced below that of the evaporator, which is needlessly high.

The experiences had from burning coal have influenced the design of oil-burning apparatus, with the result that excessive stack heights and diameters are invariably provided, and stack-gas temperatures of 500° F. (260° C.) are considered the lowest attainable. An oil fuel can be burned completely in a properly designed furnace with very little excess air and minimum draft with stack temperatures of 350° F. (176.6° C.) or less.

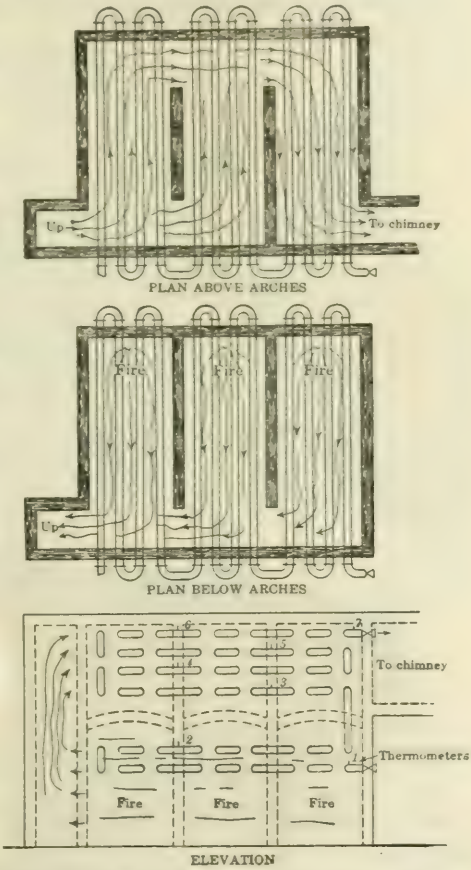


FIGURE 41.—Flue-gas flow sheet, Trumble plant No. 2 at Martinez.

The vapor flow chart comprising figure 42 shows the flow of distillates and vapors through the apparatus, and figure 43 shows the manifold by means of which the dephlegmator bottoms may be sent direct to storage or by-passed through the separators for further treatment (see also Pl. L, *B*).

The vapors leaving the evaporator pass through the oil catcher, whence the oils mechanically carried over are returned to the bottom of the evaporator. From the oil catcher they pass in series through the dephlegmator, entering near the bottom and leaving near the top. The lightest product leaves dephlegmator 6 as a vapor and passes in parallel around the tubes of 30-inch vertical condensers 1 and 2, and thence to the receiving house as gasoline.

In normal operation the bottoms of dephlegmator 1 pass around the tubes of the horizontal cooler 1, being cooled by the entering

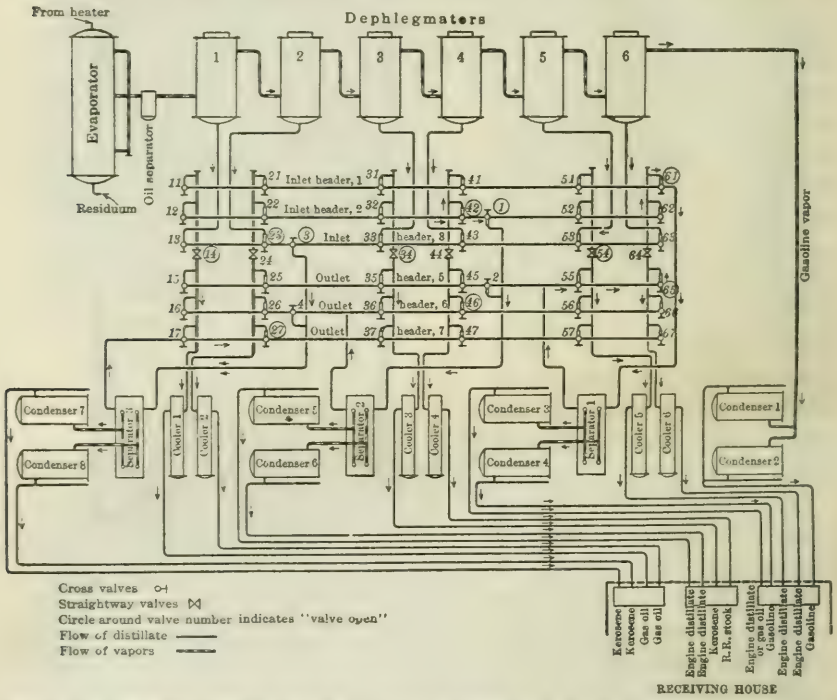


FIGURE 42.—Vapor and distillate flow sheet, Trumble plant No. 2, Martinez. Numbers are same as on valve chart, figure 43. R. R. stock, rerun stock.

crude contained in the tubes; thence the bottoms pass to storage as gas oil.

The bottoms of dephlegmator 2 flow to the liquid compartment of separator 3, a part being reevaporated by the heat of the residuum flowing through the tubes. The bottom distillate from the separator flows around the tubes of cooler 2, exchanging heat with crude, and thence to storage as gas oil.

The two vapor tops from the separator pass around the tubes of condensers 7 and 8, and after having been condensed and cooled by the water circulating through them, pass to storage as export kerosene.

The bottoms of dephlegmator 3 gravitate to cooler 3, passing around the tubes containing cold crude, and then pass to storage as export kerosene.

The bottoms of dephlegmator 4 are rerun in separator 2 by the heat of the residuum passing through the tubes. The bottom distillate from this separator is cooled in cooler 4 and stored as rerun stock.

The vapors from the separator pass around the tube of vertical condensers 5 and 6 and to storage as engine distillate. The bottoms

Valve No.	Dephlegmator 1.	
	From—	To—
11	Dephlegmator 1....	Separator 1.....
12	Dephlegmator 1....	Separator 2.....
13	Dephlegmator 1....	Separator 3.....
14	Dephlegmator 1....	Cooler 1.....
15	Separator 1.....	Cooler 1.....
16	Separator 2.....	Cooler 1.....
17	Separator 3.....	Cooler 1.....
	Dephlegmator 2.	
21	Dephlegmator 2....	Separator 1.....
22	Dephlegmator 2....	Separator 2.....
23	Dephlegmator 2....	Separator 3.....
24	Dephlegmator 2....	Cooler 2.....
25	Separator 1.....	Cooler 2.....
26	Separator 2.....	Cooler 2.....
27	Separator 3.....	Cooler 2.....
	Dephlegmator 3.	
31	Dephlegmator 3....	Separator 1.....
32	Dephlegmator 3....	Separator 2.....
33	Dephlegmator 3....	Separator 3.....
34	Dephlegmator 3....	Cooler 3.....
35	Separator 1.....	Cooler 3.....
36	Separator 2.....	Cooler 3.....
37	Separator 3.....	Cooler 3.....
1	Inlet header 2.....	Separator 2.....
2	Separator 1.....	Separator 2.....
3	Inlet header 3.....	Separator 3.....
4	Separator 2.....	Separator 3.....

Valve No.	Dephlegmator 4.	
	From—	To—
41	Dephlegmator 4.....	Separator 1.
42	Dephlegmator 4.....	Separator 2.
43	Dephlegmator 4.....	Separator 3.
44	Dephlegmator 4.....	Cooler 4.
45	Separator 1.....	Cooler 4.
46	Separator 2.....	Cooler 4.
47	Separator 3.....	Cooler 4.
	Dephlegmator 5.	
51	Dephlegmator 5.....	Separator 1.
52	Dephlegmator 5.....	Separator 2.
53	Dephlegmator 5.....	Separator 3.
54	Dephlegmator 5.....	Cooler 5.
55	Separator 1.....	Cooler 5.
56	Separator 2.....	Cooler 5.
57	Separator 3.....	Cooler 5.
	Dephlegmator 6.	
61	Dephlegmator 6.....	Separator 1.
62	Dephlegmator 6.....	Separator 2.
63	Dephlegmator 6.....	Separator 3.
64	Dephlegmator 6.....	Cooler 6.
65	Separator 1.....	Cooler 6.
66	Separator 2.....	Cooler 6.
67	Separator 3.....	Cooler 6.

Normal Operation.

Bottoms from dephlegmators 1, 3, and 5 to coolers 1, 3, and 5.
Bottoms from dephlegmators 2, 4, and 6 to separators 3, 2, and 1.
Top from dephlegmator 6 to condensers 5 and 6.
Separator 1 to cooler 6.
Separator 2 to cooler 4.
Separator 3 to cooler 2.

Figure 43.—Valve chart, distillate system, Trumble plant No. 2, Martinez. See flow-sheet, fig. 24.

of dephlegmator 5 flow through cooler 5, and thence to storage as engine distillate.

The bottoms of dephlegmator 6 are rerun in separator 1 by the heat of the outgoing residuum. The two vapors from this separator pass through vertical condensers 3 and 4 and enter storage as high-grade engine distillate. The distillate bottom from the separator

passes through cooler 6 to storage as engine distillate. In the separators, the dephlegmators, and the evaporator some steam is used, the volume being dependent on the quality of the distillate desired. Figure 44 shows the path of flow of steam through the plant.

The valve chart comprising figure 43, shows that any or all distillate products from the dephlegmators may be sent through the separators and rerun to specifications.

Figure 45 is a graphic representation of the results of distillation of the products from these dephlegmators and separators. The boiling points in the centigrade scale are plotted on the horizontal lines and the percentage going over as vapor at these temperatures

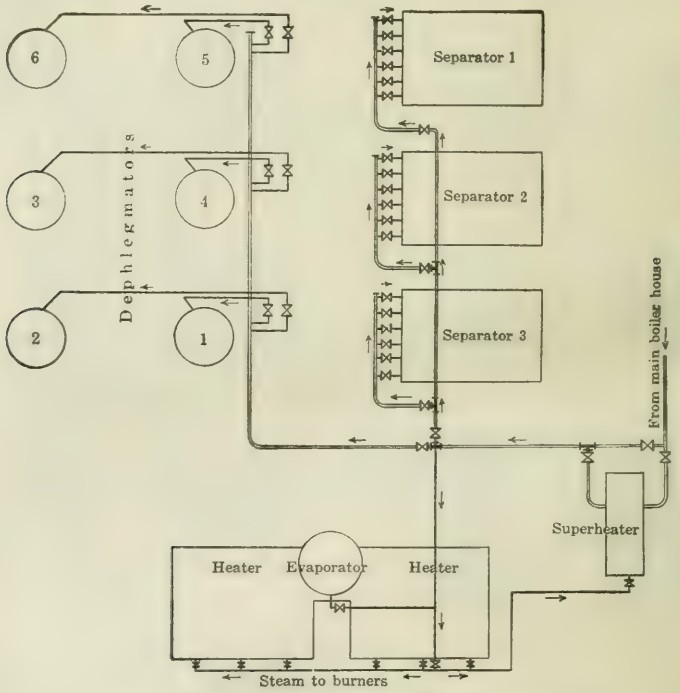


FIGURE 44.—Steam flow sheet, Trumble No. 2 plant, Martinez, Cal.

is shown on the vertical scale. For example, the curve marked T 6 D (top of dephlegmator 6) shows that at 100° C., 37 per cent of this product will leave as a vapor, that at 125° C., 45 per cent vaporizes; and that at 155° C. the final boiling point of the product is reached.

COST OF LABOR.

The two plants at Martinez are operated in conjunction, with three 8-hour shifts, each consisting of 2 stillsmen, 1 fireman, 1 pumpman, 1 helper who takes hourly samples in the tailhouse, and 1 gager on the receiving tanks. The wages total $51 a day.

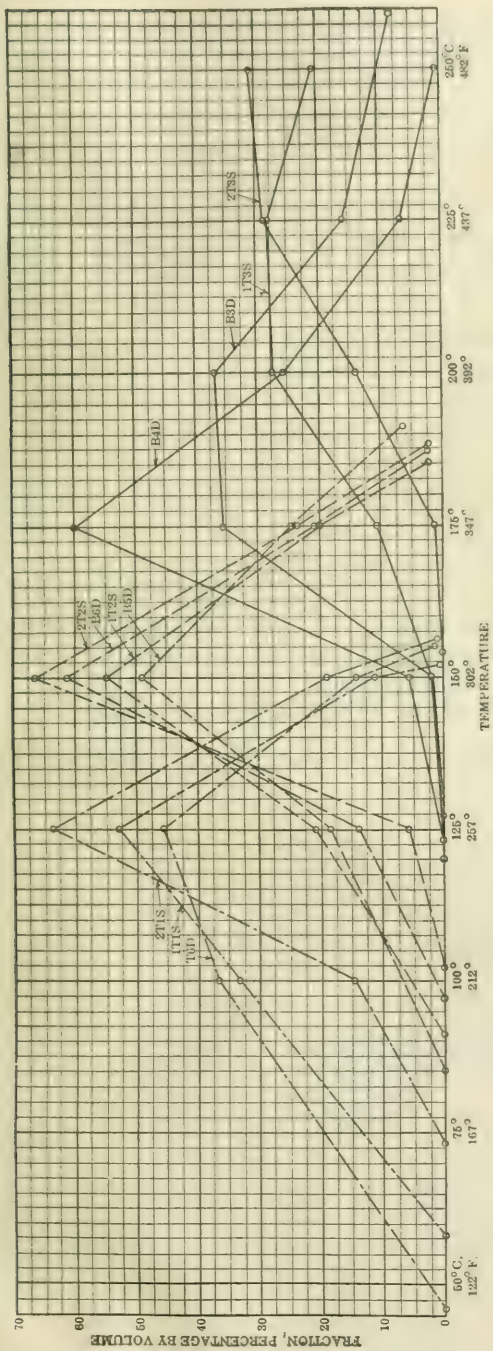


FIGURE 45.—Curves showing results of Engler distillations of products at Trumble No. 2 plant, Martinez, Cal. —·—·— gasoline. — — — engine distillate. ——— kerosene. T 6 D, top, sixth dephlegmator; 1 T 1 S, first top, first separator; 2 T 1 S, second top, first separator; B 6 D, bottom, sixth dephlegmator, B 5 D, bottom, fifth dephlegmator; 1 T 2 S, first top, second separator; 2 T 2 S, second top: second separator; B 4 D, bottom, fourth dephlegmator: B 3 D, bottom, third dephlegmator; 1 T 3 S, first top, third separator; 2 T 3 S, second top, third separator.

REPAIRS.

The plants have been operating continuously since construction, any shutdowns being due to only minor troubles or additions. The lower heater pipes on several occasions have burned out and split, causing small fires from the escape of the oil into the furnace. Repairs after a fire constituted the replacement of the bad tubes with new ones.

The performance of the heater pipes equipped with cast-iron rings does not justify their installation. Continual trouble has resulted from the excessive temperature these pipes acquire, manifested in burnt and split tubes. The greatly added weight sustained by the pipes, which frequently are red hot, causes them to sag alarmingly and either the tube splits or superheating results from accumulated sediment. Also the installation is costly and other plants not so equipped are operating at equal or better efficiency. At the Coalinga plant, after continuous operation for a year at equal or greater temperatures not a single leaky, split, or burnt-out tube has developed in the heaters. This plant is using gas fuel which is admittedly easier on a furnace, but unquestionably equally satisfactory results can be had with an oil fire if it is carefully handled. There is a distinct blast action to an oil fire; hence the flames should not impinge directly on the pipes.

RECORD OF PERFORMANCE OF PLANTS.

Table 29 following shows the results of a typical run through the two plants for one month.

TABLE 29.—*Record of one month's run, Trumble plants 1 and 2, Martinez.*

Crude oil topped by both plants.	Gravity.		Name of product.	Volume produced.	Gravity.		Percentage of product of total crude.
	°B.	Specific gravity.			°B.	Specific gravity.	
Barrels.				*Barrels.*			
51,327.96	23 to 28	0.916 to 0.987	Gasoline	10,660.53	58	0.747	2.4
279,896.18	22 to 23	.922 to .916	Engine distillate	10,064.47	50	.779	2.3
103,658.52	20	.934	Domestic kerosene	475.19	44	.806	.1
434,882.66			Export kerosene	33,122.99	39.5	.827	7.6
			Stove distillate	25,891.31	33	.859	5.8
			Residuum	350,658.86	17 to 21	0.953 to .928	80.

Fuel consumed, per cent of crude run		1.
Refining loss	barrels	4,109.3
Refining loss	per cent	.9
Steam consumed, pounds of water		2,811,51
Boiler horsepower developed per day		11
Cooling water used	barrels	2,174,40

COST OF PLANT.

Following is a tabulation of the cost of construction of the No. 2 plant, based on the cost of material in 1915:

Cost of construction of Trumble plant No. 2, Martinez.

Three inspection boxes	$1,125.83	
Six 30-inch coolers, three 6 by 18 foot separators, eight 30-inch vertical condensers	10,006.95	
Five 48-inch heat exchangers, and six dephlegmators	4,098.00	
One 6 foot by 25 foot evaporator	842.50	
One 12-inch oil separator	265.00	
One 470-barrel fuel oil tank	558.50	
Two 2,800-barrel residuum tanks	3,945.90	
Five 1,000-barrel distillate receiving tanks	5,472.50	
Miscellaneous equipment	55.45	
Building and platforms	5,720.34	
Heaters and brickwork	4,010.34	
Pipe and fittings	13,850.84	
Excavation, foundations and erecting labor	17,591.57	
Total	69,178.18	
Ten per cent for engineering and supervision	6,917.81	
		$76,095.99

The cost of construction, omitting the cost of the tankage, is approximately $8.80 per barrel of capacity, which compares favorably with the other plants described herein and is somewhat lower than that of the conventional still set when the cost of material at the time of building is considered.

POSSIBLE CHANGES AND IMPROVEMENTS.

In the writer's opinion a combination of these two plants would effect the most practicable operating arrangement. The crude could then be heated fractionally by operating the heaters in series in conjunction with the evaporator column, and the products fractionally cooled by the series of dephlegmators used in the second plant. With light oil this arrangement would be particularly desirable, because of the large quantity of vapors that otherwise would be superheated when running to a residual fuel oil.

Also, the design and construction of the heaters undoubtedly could be improved (1) by rearranging the baffling as before mentioned to increase the velocity of the gases and make them flow countercurrent to the oil, (2) by preheating the air for combustion through absorption of some of the waste heat radiated from the setting, and, possibly (3) by supporting the coils at their center. It is not uncommon for the lower coils to sag fully a foot under fire, a condition which can not fail to weaken the tubes and invite deposits with consequent local superheating and burning. Careful firing will prevent this

trouble, but the middle support could be arranged as an oil-containing coil in series with the main coil, and thus render the heater less susceptible to damage from careless or inexperienced operation.

However, on the whole, such plants are economical in operation, low in first cost, can be quickly built, and every advantage is taken of the heat recovered, as the following theoretical computations show:

DISTILLATION.

The approximate fractions by volume distilling over at the different boiling points are given in the following average sample:

Composite sample of crude oil, gravity, 22° B. (specific gravity, 0.922).

Boiling points.		Specific gravity of fraction.	Percentage vaporized—		Specific gravity of residue.	Percentage of residue—	
°F.	°C.		By volume.	By weight.		By volume.	By weight.
100 to 225	37.7 to 107.2	0.730	1.86	1.25	0.927	98.14	98.75
225 to 250	107.2 to 121.1	.750	1.50	1.03	.929	96.64	97.72
250 to 300	121.1 to 148.8	.770	3.71	2.64	.935	92.93	95.08
300 to 350	148.8 to 176.6	.820	5.19	3.92	.942	87.74	91.16
350 to 400	176.6 to 204.4	.850	5.50	4.32	.948	82.24	86.84
400 to 450	204.4 to 232.2	.855	1.00	0.79	.950	81.24	86.05

THEORETICAL FUEL CONSUMPTION.

The quantity of heat required per pound of this oil to remove the above fractions, assuming that no heat loss occurred in the apparatus and considering the heat recovered by the exchangers, would be as follows:

Where the specific heat of the oil is 0.45, approximately,
specific heat of the vapors is 0.50, approximately,
latent heat of the distillate is 125 B. t. u., approximately,
oil leaves the last exchanger at 225° F. (107.2° C.).

		British thermal units.
Heat 0.988 pounds of oil 225 to 250° F. (107.2 to 121.1° C.)	0.988 (225–250)×0.45=	11.21
Evaporate 0.013 pounds of vapors	.013 ×125 =	1.63
Superheat 0.023 pounds of vapors 225 to 250° F. (107.2 to 121.1° C.)	.023 (225–250)×0.50=	0.03
Heat 0.977 pounds of oil 250 to 300° F. (121.1 to 148.8° C.)	.977 (250–300)×0.45=	22.00
Evaporate 0.026 pounds of vapors	.026 ×125 =	3.25
Superheat 0.049 pounds of vapors 250 to 300° F. (121.1 to 148.8° C.)	.049 (250–300)× .50=	1.25
Heat 0.951 barrels of oil 300 to 350° F. (148.8 to 176.6° C.)	.951 (300–350)× .45=	21.40
Evaporate 0.039 pounds of vapors	.039 ×125 =	4.87
Superheat 0.088 pounds of vapors 300 to 350° F. (148.8 to 176.6° C.)	.088 (300–350)× .50=	2.20

		British thermal units.
Heat 0.912 pounds of oil 350 to 400° F. (176.6 to 204.4° C.)	0.912 (350–400) × 0.45	=20.50
Evaporate 0.043 pounds of vapors	.043 × 125	= 5.37
Superheat 0.131 pounds of vapors 350 to 400° F. (176.6 to 204.4° C.)	.131 (350–400) × .50	= 3.27
Heat 0.868 pounds of oil 400 to 450° F. (204.4 to 232.2° C.)	.868 (400–450) × .45	=19.32
Evaporate 0.008 pounds of vapors	.008 × 125	= 1.00
Superheat 0.139 pounds of vapors 400 to 450° F. (204.4 to 232.2° C.)	.139 (400–450) × .50	= 3.48

Total heat required to top 1 pound of this oil at 100 per cent efficiency=120.78 or as 22° B. (0.922) gravity oil weighs 322.5 pounds per barrel, to top 1 barrel at 100 per cent efficiency would require 322.5×120.78=38951.55 B. t. u., or 9,800 calories.

Actually the plant consumed 0.011 barrel of fuel for each barrel of oil topped, as shown in Table 28, or with 18° B. (0.946) gravity fuel oil, 68,325.4 B. t. u., or 17,219 calories.

OVER-ALL EFFICIENCY OF THE RETORTS.

Therefore the combined over-all efficiency of both batteries of retorts is $\frac{38,951.55}{68,325.4}=\frac{19,800 \text{ calories}}{17,219 \text{ calories}}=57.0$ per cent.

HEATER DATA.

The data showing the relative transfer of heat in the different banks of coils in the heaters, is presented in Table 30. The positions of the thermometers used for these readings are shown in figure 41. The table brings out the large heat transfer in the two lower rows of pipes as compared with the small temperature rise in the top row. A countercurrent flow of oil and flue gases would result in an even temperature increment at each successive row of pipes and cool the gases more nearly to the temperature of the entering oil, which would save fuel and increase the plant efficiency.

TABLE 30.—*Data on heaters at Trumble plant No. 2, Martinez, Cal.*

August, 1916.

[In each set of observations, first line shows degrees Fahrenheit; second line, degrees centigrade.]

Thermometer No.[a]	9.30 a. m.		10 a. m.		10.30 a. m.		11 a. m.		12 noon.		1 p. m.		1.30 p. m.		2 p. m.		3 p. m.		4 p. m.	
	Temperature.	Rise.[b]	Temperature.	Rise.[b]	Temperature.	Rise.[b]	Temperature.	Rise.[b]	Temperature.	Rise.[b]	Temperature.	Rise.[b]	Temperature.	Rise.[b]	Temperature.	Rise.[b]	Temperature.	Rise.[b]	Temperature.	Rise.[b]
1	198		197		197		217		219		221		220		220		219		219	
	92.2		91.6		91.6		102.7		103.8		105		104.4		104.4		103.8		103.8	
		107		109		112		93		95		94		93		92		95		98
		59.4		60.8		62.2		51.7		52.8		52.2		51.7		51.1		52.8		54.5
2	305		306		309		310		314		315		313		312		314		317	
	151.6		152.2		153.8		154.4		156.6		157.2		156.1		155.5		156.6		158.3	
		30		30		30		31		31		30		30		31		32		32
		16.7		16.6		16.7		17.2		17.2		16.7		16.6		17.2		17.8		17.8
3	335		336		339		341		345		345		343		343		346		349	
	168.3		168.8		170.5		171.6		173.8		173.8		172.7		172.7		174.4		176.1	
		30		30		30		30		30		30		31		31		30		40
		16.7		16.7		16.7		16.7		16.7		16.7		17.3		17.2		16.7		22.2
4	365		366		369		371		375		375		374		374		376		389	
	185		185.5		187.2		188.3		190.5		190.5		190		190		191.1		198.3	
		10		10		10		10		10		10		9		9		10		0
		5.5		5.5		5.5		5.5		5.6		5.6		5.0		5.0		5.5		
5	375		376		379		381		385		385		383		383		386		389	
	190.5		191.1		192.7		193.8		196.1		196.1		195		195		196.6		198.3	
		25		26		26		26		26		25		27		26		25		27
		13.9		14.5		14.5		14.5		14.4		13.9		15		14.4		13.9		15.0
6	400		401		405		407		411		410		410		409		411		416	
	204.4		205.5		207.2		208.3		210.5		210		210		209.4		210.5		213.3	
		3		2		2		2		2		3		3		4		3		2
		1.7		1.1		1.1		1.1		1.1		1.6		1.6		2.2		1.7		1.1
7	403		403		407		409		413		413		413		413		414		418	
	206.1		206.1		208.3		209.4		211.6		211.6		211.6		211.6		212.2		214.4	

[a] See figure 41, p. 143, for position of thermometers.

[b] Shows temperature rise from one reading to next reading.

GENERAL DATA.

For location of thermometers see figure 41 (p. 143).

Quantity of crude oil heated, 10,000 barrels in 24 hours, of oil of 25.7° B. (0.900) gravity.

Quantity passed through one heater, 1,093 pounds per minute.

Total length of pipe in one heater, 1,461 feet.

Total length of pipe in one heater exposed to heat, 1,136 feet.

Total area heating surface, 1,486.8 square feet.

Total average rise of temperature, 197° F. (91.65° C.)

Total time required for oil to travel through one heater, 6 minutes and 40 seconds.

Velocity of oil, 3.66 feet per second.

Percentage of total area of pipe exposed to heat, 77.75 per cent.

Average square foot of heating surface for each 1° F. rise between thermometers—

	Square feet.
1 and 2	3.6
2 and 3	7.88
3 and 4	8.64
4 and 5	25.91
5 and 6	9.97
6 and 7	57.59

SUMMARY.

Records of the various plants are summarized in Table 31, for the purpose of comparison and to point out some of the most important items.

TABLE 31.—*Summary of topping-plant records showing fuel consumption and products made.*

Name of plant.	Average per month.										
	Gross barrels of crude run.	"Tops" made.		Water dehydrated.[a]		Residuum made.		Refining loss.		Fuel consumed under stills.	
		Barrels.	*P. ct.*	*Barrels.*	*P. ct.*	*Barrels.*	*P. ct.*	*Barrels.*	*P. ct.*	*Barrels.*	*P. ct.*
Conventional stills	401,853.1	96,690	24.1	.....	.....	300,890	74.8	2,206.4	0.55	4,507.5	1.1
A. F. I. Bell	186,971	45,250	24.1	5,609.1	3	139,000	74.8	1,082	.55	2,987.1	1.6
Brea plant	169,330	26,300	15.5	5,210	3.08	135,000	79.8	2,823	1.67	.....	.....
I. W. Fuqua	239,708	26,294	11	.....	.....	.....	.....	.....	.....	.....	1.6
E. I. Dyer	228,955.1	32,340	14.2	46,638	20.7	138,765.9	60.5	1,608	.70	None.	.....
Brown-Pickering	87,000	5,250	6	15,750	18	66,000	75.9	.....	.....	.....	.....
Pritzman	55,860	14,166.7	25.4	6,670	12	32,160	57.8	1,400	2.5	.....	.....
Fellows Trumble	151,978	17,940	11.8	.....	.....	.....	.....	6,380	4.2	1,400	.92
Vernon Trumble	305,205	25,900	8.5	.....	.....	.....	.....	.....	.....	2,524	.90
Coalinga Trumble	57,925	12,450	21.5	.....	.....	45,126.5	77.9	318	.55	5,100	.88
Martinez Nos. 1 and 2	434,882	114,800	18.4	.....	.....	350,658	80.5	4,109	.94	4,780	1.1
Total	2,319,667.2	417,380.7	18	.....	.....	1,207,600.4	.....	21,390.4	.86	212,986	.....
Average	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

[a] Records of water dehydrated were not available for all the plants.

TABLE 31.—*Summary of topping-plant records showing fuel consumption and products made*—Continued.

Name of plant.	Computed percentage of fuel consumed under boilers per barrel of crude run.	Percentage of fuel used in rerunning, per barrel of crude.	Total percentage of fuel used, per barrel of crude.	Boiler horsepower of steam per barrel of "tops."	Barrels of cooling water used per barrel of "tops" made.	Cost of plant per barrel of daily capacity.
Conventional stills	0.88	0.23	2.13	4.1	14.0	$16.80
A. F. L. Bell	.55	.23	2.38	2.80	14.0	12.80
Brea plant	.....	.....	.....	.....	.....	.....
I. W. Fuqua	[a] .50	[a] .15	2.25	.....	12.5	7.00
E. I. Dyer	.....	.....	.....	.....	20.7	28.55
Brown-Pickering	.....	.....	.....	.....	.....	.....
Prutzman	.....	.....	.....	.....	.....	.....
Fellows Trumble	.....	.....	.....	.....	.....	2.00
Vernon Trumble	.24	.....	1.14	3.0	.....	5.80
Coalinga Trumble	[a] .19	.....	1.07	.....	15.0	7.48
Martinez Nos. 1 and 2	.12	.....	1.23	.72	20.7	8.50
Total	.....	.....	.....	.....	.....	.....
Average	.....	.....	2.01	.....	.....	.....

[a] Figures estimated.

NOTE.—Under the column for "Total fuel consumption" the reader should note that the plants are all making a different percentage of distillate to the crude treated and in addition some are dehydrating the oil.

The column for "total fuel consumption" shows that the percentage of fuel used to a barrel of crude treated varies widely at the different plants. This variation is partly due to the differences in the size of distillate fraction vaporized and in the degree of dehydration in the various plants, and also in large part to the difference in efficiency of apparatus used. The average figure is practically 2 per cent for the representative plants, and is perhaps considerably better than an average for all active topping plants would be. However, it is evident from the table that the fuel consumption can be even materially reduced below this figure. A reduction of 0.75 of 1 per cent for the plants cited would amount to a saving of 17,400 barrels of fuel oil each month.

The column for "refining loss" also shows a considerable range, the average loss being about 0.86 of 1 per cent of the crude run.

Any considerable refining loss is inexcusable about a plant when the uncondensed vapors used, constituting the major part of the loss, might be recovered by passing them through absorption towers against the heavy distillate produced. Experiments have demonstrated that even some of the gas leaving a compressor plant may be recovered in an absorption tower by washing the gas with distillate. The gases are dissolved in the distillate and have the effect of raising the Baumé gravity. However, in the choice of menstruum it must be noted that the gas dissolved can not be condensed upon redistillation. Hence, the product would have to be regulated to conform with marketable conditions by other means than redistilling. The vapors and gases constitute some of the most valuable fractions in the oil, and their recovery should be imperative.

The costs per barrel of capacity show that the choice of type is of considerable importance. The pipe retorts are uniformly cheaper in first cost. The consideration of a few salient points concerning heat transfer will explain the reason for this lower cost.

In any type of still, heat transfer is by convection, radiation, and conduction. Of these, convection and radiation are the most important, the conductivity of oil being very low. The principle of convection is based on the theory that the fluid to be heated and the gas giving up heat consist of infinitely small particles. Particles of hot gas come in contact with the shell container momentarily, give up their heat to the shell, and make way for succeeding particles. The shell transmits the heat to the particles of oil in contact with it, which then make way for other cold particles. The iron shell has a high rate of conductivity.

Convection is greatly facilitated by passing the hot and cold bodies at high velocity through small cross-sectional passages. Therefore, the rate of heat transfer per square foot of surface is much higher in pipe retorts than in the conventional still, and less heating surface is required. In heating a body of water, the rapid circulation induced greatly assists convection. As petroleum is composed of many hydrocarbons differing in gravity, circulation is not a material factor with oil, and when heated in large containers some agitating agent, such as steam, must be used to prevent overheating the oil adjacent to the shell.

However, every oil requires different treatment and a plant adapted to its requirements. The conventional stills, in the writer's opinion, will, under average operating conditions, distill a larger and cleaner fraction from the oil than the pipe retorts, and their installation does not require a separating chamber for the vapors and oil. With proper provisions for recovery of heat from the flue gases, etc., the thermal efficiency of a battery of conventional stills should be as high as with pipe retorts.

Cooling-water requirements vary in the different plants, owing partly to difference in conditions and partly to differences in heat recovery from the vapors. In a plant using water repeatedly through cooling towers, the temperature to which it is heated in the condensers must be governed by the amount it is cooled in the towers. On the contrary, a plant that does not have to reuse its water can discharge it at a much higher temperature. Any method for increasing heat recovery from the vapors will, of course, reduce cooling-water requirements.

In conclusion, the reader's attention is called to the difficulty of drawing a close comparison between the various plants. The conditions for any particular plant are so variable that the choice of plant should be contingent on careful study from all angles. The writer has endeavored to describe fully the various plants, drawing attention to commendable features, with modifications to suit requirements which might be incorporated in other installations, and having due regard to patent rights.

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INDEX.

A.

Page.

Air for combustion, excess of, losses by ... 14
preheating of, advantages of ... 32
Avila, Cal., Dyer plant at, cost of ... 80–81
description of ... 71–75
figures showing ... 75, 77, 79, 80, 82, 83, 84
operation of ... 74–81
products of ... 77–78
temperatures in ... 77–79
views of ... 58, 74, 75, 76
Avon, Cal., Bell-design plant at, arrangement of, figures showing ... 22
cost of ... 31–32
description of ... 16–25
distillation of gasoline at ... 29
labor costs in ... 31
materials for, list of ... 18
operation of ... 25–26
possible improvements of ... 32
refinery, products of ... 27, 29
refining loss at ... 28
repairs at ... 31
views of ... 22, 24, 36, 38
volume of oil run and of products ... 28, 29
conventional still plant at, cost of ... 11
description of ... 4–6
fractionations of oil sample from ... 12
fuel consumption of ... 10
furnace and stack temperatures in ... 12
operation of ... 6–10
operating cost of ... 10

B.

Baumé scale, use of ... 2
Beers, H. H., acknowledgment to ... 3
Bell, A. F. L., acknowledgment to ... 3
Betteravia, Cal., Prutzman plant at, description of ... 85–87
details of, figure showing ... 86, 87, 88, 90
operation of ... 87–88
products of ... 88
views of ... 88, 90
Boiler and tanks, Coalinga plant, description of ... 118
Boiling points of condensates, Avon plant ... 8
"Bottoms," steam still, at Avon refinery ... 29
Brea, Cal., plant at, capacity of ... 45
cost of operation of ... 46
description of ... 38–43
details of, figures showing ... 40, 42
efficiency of ... 47
fuel consumption of ... 45
oils handled by ... 45
operation of ... 44–47
possible improvements in ... 47
repairs at ... 46
views of ... 40, 50

Page.

Brown-Pickering plant, capacity of ... 85
description of ... 81–84
details of, figures showing ... 82, 83
operation of ... 84–85
repairs needed at ... 85
views of ... 86–88

C.

Coalinga, Cal., Trumble plant at, arrangement of, figures showing ... 111, 112, 113, 114, 115, 116, 117
cost of ... 130
description of ... 110–118
distillation of gasoline at ... 123, 124
efficiency of ... 129
operation of ... 118–120
products of ... 121
refining loss at ... 121
temperatures in ... 122
view of ... 112
volume of gasoline made at ... 121
Condensers, Avila plant, description of ... 75
figure showing ... 80, 82
views of ... 74
Avon Bell-design plant, description of ... 16–22
materials for, list of ... 28
pipe and fittings for, specifications for ... 21
Avon conventional still plant, description of ... 4–5
Betteravia plant, description of ... 87
figure showing ... 87
Brea plant, figure showing ... 42
Brown-Pickering plant, description of ... 82
view of ... 87
Coalinga plant, description of ... 112
figures showing ... 97, 98
Fellows Fuqua plant, details of, figure showing ... 51
materials for, list of ... 52
Martinez, Trumble No. 1 plant, description of ... 133
view of ... 133
Vernon Trumble plant, description of ... 97
view of ... 88
Condenser piping, Avon plant, arrangement of, view of ... 28
Coolers, Brea plant, description of ... 42
Coalinga plant, description of ... 115
Martinez, Trumble No. 1 plant, description of ... 133
Trumble No. 2 plant, description of ... 138–139
Vernon plant, description of ... 98
Cooling towers, Coalinga plant, description of ... 117
Cooling water used at plants, amount of ... 154
Cost, treatment, at all plants ... 154
See also plants named.

Page.

Crude oil, approximate analysis of, Fellows Fuqua plant ... 69
fractional distillation of, Avila plant ... 77
Avon refinery ... 36
Coalinga plant ... 129
Fellows Fuqua plant ... 57–58
Martinez plants ... 150
Vernon plant ... 104–106
gravity of, Avon refinery ... 25
Betteravia plant ... 88
Brea plant ... 45
Coalinga plant ... 121, 122, 127
Martinez Trumble plants ... 148
Vernon Trumble plants ... 103
weight of barrel of ... 13, 37, 108

D.

Dephlegmators, Brea plant, description of ... 43
figure showing ... 42
Coalinga plant, description of ... 114
figure showing ... 100
Martinez Trumble No. 1 plant, description of ... 133
Trumble No. 2 plant, description of ... 129
Vernon Trumble plant, description of ... 99
Distillate, cost of producing, Fellows plant ... 60
fractionation of, Fellows plant ... 57
gravity of, Avila plant ... 77–79
Betteravia plant ... 88
Brea plant ... 45
Coalinga plant ... 125
Fellows plant ... 56, 62
Distillate cooler, Coalinga plant, figure showing ... 140
Distilling apparatus, efficiency of, definition of. 1
Draft, stack, in oil-burning furnaces, control of ... 14
Dyer, E. I., acknowledgment to ... 3
Dyer plant. *See* Avila, Cal., Dyer plant at.

E.

Efficiency, plant. *See* Avila, Cal., Avon, Cal., and other plants named.
Engler distillations of crude oil and products, Avon, Cal., plant ... 8, 26, 58, 123, 148
See also Crude oil and plants named.
Evaporator, Coalinga plant, description of ... 112
Martinez Trumble No. 2 plant, description of ... 138
figure showing ... 142
Vernon plant, description of ... 94–95
figure showing ... 95
view of ... 95

F.

Fellows, Cal., Fuqua plant at, capacity of ... 47
cost of ... 71
costs at ... 60
description of ... 47–54
details of, figure showing ... 49, 50, 51, 54, 67
efficiency of ... 69
flow chart of, figure showing ... 56
operation of ... 54–71
repairs at ... 71
temperatures in ... 61, 62, 64

Page.

Fellows, Cal., Trumble plant at, description of 89
details of, figure showing ... 90
operation of ... 89–90
cost of ... 90–93
volume of gasoline made at ... 92
Flow sheet, Avila plant, figure showing ... 74
Coalinga plant, figure showing ... 117
Fellows Fuqua plant, crude oil and residuum, figure showing ... 54
vapors and cooling water, figure showing ... 54
Martinez plants, figures showing ... 136, 141, 142, 143, 144, 146
Vernon plant, figures showing ... 101, 102
Flue gas, analysis of, Avila plant ... 80
Avon refinery ... 34
Formulas used in combustion computations. 35
Fractionations, laboratory, of distillate, Fellows, Cal., Fuqua plant ... 58
Vernon plant ... 105, 106
Fuel consumption at all plants ... 153
at Avon plants ... 10, 35–36
at Brea plant ... 46
at Coalinga refinery ... 128
at Fellows Fuqua plant ... 67
at Martinez plants ... 150
at Vernon refinery ... 103, 104–107
chart for computing ... 68
Fuel oil, Avon refinery, analyses of ... 11, 35
Fuqua, I. W., plant of. *See* Fellows, Cal., Fuqua plant at.
Furnace efficiencies, Avon conventional still plant ... 12
Furnace temperatures, Avon Bell-design plant ... 34
Avon conventional still plant ... 12

G.

Gasoline, Avon refinery, distillation of ... 29
volume of ... 29
Coalinga plant, distillation of ... 123, 124
gravity of ... 122, 128
volume of ... 121, 128
Fellows Trumble plant, volume of ... 94
Martinez plants, gravity of ... 148
volume of ... 148
Martinez Trumble plant No. 2, curves showing results of distillation of ... 147
Vernon plant, distillation of ... 105–106
Gaviota, Cal., plant at ... 16
oils handled by ... 27
Gravity, crude oil, Avila plant ... 78
Avon refinery ... 28, 36
Betteravia plant ... 88
Brea plant ... 45
Coalinga refinery ... 121, 123, 125, 127
Fellows Fuqua plant ... 58–59
Martinez Trumble plant ... 148
Vernon refinery ... 103, 108
distillate, Avila plant ... 78
Avon refinery ... 8–9
Betteravia plant ... 90
Brea plant ... 45
Coalinga refinery ... 125
Fellows plant ... 57
Vernon plant ... 103

Page.
Gravity, gasoline, Coalinga refinery . . . 122, 125
oils, Avon refinery 7
products, Avon refinery 29
Martinez plant 148
residuum, Avila plant 78
Betteravia plant 90
Coalinga refinery 121, 125
Vernon refinery 108
"tops," Avon refinery 28

H.

Heat economizer, Betteravia plant, description of 87
details of, figure showing 90
Heat exchangers, Avila plant, description of . . 72
details of, figure showing 74
efficiency of 78
materials for, list of 76
views of 74, 75, 76
Avon, Bell-design plant, arrangement of, figure showing 22
details of 21
figure showing 30
list of materials for 24
Avon conventional still plant, description of 4–5
Betteravia plant, description of 86
Brea plant, description of 41
Brown-Pickering plant, description of . . . 85
view of 87
Coalinga plant, description of 112
view of 112
Fellows Fuqua plant, details of 66
Martinez Trumble No. 1 plant, description of 133
view of 133, 134
Trumble No. 2 plant, description of . . 138
view of 142
Vernon plant, description of 97
efficiency of 107–108
figures showing 97
view of 94
Heat losses, Avon refinery 12
Heat losses from excess air for furnaces 14
Heat-transfer calculations, Avon refinery 14, 36
Brea plant 47
Coalinga plant 126
Fellows Fuqua plant 65–66
Heater, Betteravia plant, description of 87
Coalinga plant, description of 111–113
crude oil, Fellows Fuqua plant, description of 48
figure showing 49
temperatures in 62
Martinez Trumble No. 1 plant, description of 130–131
Trumble No. 2 plant, description of . . 138
heat transfer in 151, 152
Vernon plant, description of 94, 98, 99

K.

Kerosene, Martinez plants, gravity of 148

L.

Lansche, H. M., acknowledgment to 3

M.

Page.
Martinez, Cal., Trumble plants at, description of 130–153
efficiency of 150–151
gasoline made at, volume of 148
labor costs at 148
possible improvements 149
repairs at 148
Trumble plant No. 1, details of, figures showing 113, 115, 116
operation of 134, 137
views of 132, 133, 134
Trumble plant No. 2, cost of 159
details of, figures showing 131, 132, 124, 135, 136, 139, 140, 141, 142, 143, 144, 145, 146, 147
curves showing results of distillations of gasoline at 147
fuel consumption at 150
operation of 140–151
views of 138, 140, 142, 143
Miller, Walter, acknowledgment to 3
Milliff, Frank, acknowledgment to 3

N.

Naramore, Chester, acknowledgment to 3

O.

Oil catcher, Coalinga plant, description of . 114, 115
figure showing 116
Martinez Trumble No. 1 plant, description of 131–134
Trumble No. 2 plant, description of . . 140
Oil warmers, Fellows Fuqua plant, description of 54

P.

Peterson, W. H., acknowledgment to 8
Pipe heaters, Martinez Trumble No. 2 plant, view of 140
Pipe retorts, Betteravia plant, view of 98
Brea plant, description of 38–39
figure showing 39
views of 40
Coalinga plant, figures showing 111, 113
Martinez Trumble No. 1 plant, figures showing 95, 96
Trumble No. 2 plant, views of 132, 133
Vernon plant, figure showing 99
views of 95, 97
Prewarmers, advantages of 15
Brown-Pickering plant, description of . . . 82
Prutzman, Paul, acknowledgment to 3
Prutzman plant. *See* Betteravia, Cal., Prutzman plant at.

R.

Refining loss in plants 153
Martinez plants 148
Rerunning plant, Avon Bell-design plant, operation of 27
Avon conventional still, cost of 11
Brea plant, description of 44
Fellows Fuqua plant, operation of 55
Residuum coolers, Avon conventional still plant, description of 6

Page.
Residuum, gravity of, Avila plant..... 77
Betteravia plant..... 88
Coalinga plant..... 121, 125
Fellows Fuqua plant..... 63
Martinez plants..... 148
Vernon refinery..... 108
Residuum made at topping plants, amount of 153
Retorts, Avon, Bell-design plant, details of.. 16–17
Fellows plant, view of..... 51
Ripley, E. P., acknowledgment to..... 3

S.

Senden, G. Van, acknowledgment to..... 3
Separating towers, Avon, Bell-design plant, details of..... 19, 23
view of..... 26, 36
Brea plant, description of..... 40
view of..... 49
Fellows Fuqua plant, elevation of, figure showing..... 50
plan of, figure showing..... 51
Separator, Brown-Pickering plant, description of 84
Coalinga plant, description of..... 112–114
figure showing..... 113
Fellows Fuqua plant, description of 49
Martinez Trumble No. 1 plant, description of..... 131–132
Trumble No. 2 plant, description of.. 138
Vernon plant, figure showing..... 96
view of..... 96
Vapor, Brea plant, description of..... 41
Shumate, J. G., acknowledgment to..... 3
Stack draft in oil-burning furnaces, reduction of..... 14
Stamm, Chris, acknowledgment to..... 3
Steam consumption, Avon refinery..... 29–30
Fellows Fuqua plant..... 69
Steam production, Avila plant, data on..... 79
Stills, at all plants, efficiency of..... 154
at Avila plant, description of..... 72
boiler, at Brea plant, description of..... 39
view of..... 41
combination, at Avon Bell-design plant, details of..... 25
materials for, list of..... 26
at Brea plant, figure showing..... 38
conventional, Avon refinery, capacity of. 9
description of..... 4, 5
efficiency of..... 13
figures showing..... 6, 8
fuel consumption of..... 28
heat losses of..... 12
view of..... 10
oil lines for, Brea plant, diagrams showing..... 40
piping of, Avila plant, view of..... 84

Page.
Stills, rectangular, Brown-Pickering plant, description of..... 81
figure showing..... 82
views of..... 86
rerunning, Avon refinery, description of. 8
steam, Avon Bell-design plant, details of. 23
piping of, figures showing..... 32, 34
view of..... 24
Betteravia plant, description of..... 86
figure showing..... 86
Stove distillate, output of, at Martinez plants. 148
Stove oil, output of, at Avon refinery..... 29

T.

Temperatures, Avila plant..... 79
Avon refinery..... 7, 12, 13, 34, 37
Coalinga refinery..... 118, 122, 125
Vernon refinery..... 108
Thompson, N. W., acknowledgment to..... 3
Topping, purpose of..... 1–2
Topping plants, definition of..... 1
fuel consumption in..... 153
output of..... 153
Topping retort, Avon Bell-design plant, figure showing..... 16, 18
views of..... 22, 24
"Tops" at all topping plants, amount of..... 153
Avon refinery, gravity of..... 28
Trumble plants. *See* Coalinga, Cal., Fellows, Cal., Martinez, Cal., Vernon, Cal.

V.

Valve chart, distillate system, Martinez Trumble No. 2 plant, figure showing..... 145
Vernon, Cal., Trumble plant at, cost of..... 110
cost of operation of..... 109
description of..... 94–100
details of figures showing..... 95, 96, 98, 99, 100, 101, 102
distillation of gasoline at..... 105, 106
efficiency of..... 107
fuel consumption of 106–109
operation of..... 100–103
products of..... 103–106
temperatures in..... 103
views of..... 88, 93, 94, 96

W.

Water consumption, Avon refinery..... 9, 30
Fellows plant..... 70
Water-cooling towers, Fellows plant, view of. 49
Water traps, Coalinga plant, description of.. 116
Weight of barrel of crude oil, Avon refinery.. 13, 37
Vernon refinery..... 108
Williams, W. A., acknowledgment to..... 3